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ABSTRACT

Written to be used concurrently with the U.S. Army's Radiological Safety Course, this publication discusses the causes, sources, and detection of nuclear radiation. In addition, the transportation and disposal of radioactive materials are covered. The report also deals with the safety precautions to be observed when working with lasers, microwave generators, and particle accelerators. Work problems with solutions are provided for those topics mentioned. (CP)

RADIOLOGICAL SAFETY HANDBOOK

COURSE ____________________

NAME ____________________

U.S. ARMY ORDNANCE CENTER AND SCHOOL, ABERDEEN PROVING GROUND, MARYLAND

INDEX

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FOREWORD TO STUDENTS

This Radiological Safety Handbook is a study aid for students attending the Radiological Safety Course instructed by the NBC Division, Chemical and Ground Support Training Department, U.S. Army Ordnance Center and School, Aberdeen Proving Ground, MD 21005. It should prove invaluable in providing students with the practical knowledge of solving problems pertinent to radiological safety - a must for the completion of this course -- and will be a valuable asset for on-the-job reference.

Subjects are presented numerically according to their file numbers, with pages within each lesson numbered in sequence.

Each lesson file number is presented in five parts as applicable.

I. References and/or Discussion.

II. Lesson Objectives and Notes.

III. Laboratory Exercise and/or Handouts.

IV. Problems.

V. Solutions to Problems.

Because there may be several correct methods of solving the problems, the solutions given are for only one method. Other methods may be equally valid but may give a slightly different numerical answer; reasonable agreement, though, is necessary.

This publication has deliberately been slanted toward a specific objective; there is no claim of its being exhaustive or all-inclusive. Instructors will be happy to recommend other references when further information is desired or required.

The NBC Division welcomes any comments or corrections concerning this handbook.

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RADIATION SAFETY PRECAUTIONS.

A. Radiation Hazards.

To train personnel properly in the use and operation of radiac instruments, radioactive materials are used in many of the exercises conducted in the Radiological Laboratories. There is a health hazard involved when these radioactive materials are used. Safety measures have been prescribed so that these hazards may be reduced to a safe limit. An office has been set up to insure that these safety measures are carried out. This organization is known as the Health Physics Division.

B. Safety Procedures.

1. The fundamental purposes for radiation safety measures are:

   a. to prevent ingestion, inhalation, or other entry of radioisotopes into the body,

   b. to maintain the amount of external exposure to ionizing radiation below permissible limits, and

   c. to minimize the exposure of personnel to harmful ionizing radiation.

2. The prescribed radiation safety precautions used at the U. S. Army Ordnance Center and School include the following:

   a. Personnel will wear film badges for all laboratory periods. These film badges are initially signed for by students in the home classroom. For all classes requiring film badges, students obtain them from the film badge racks outside the scaler lab (classroom T). These racks contain numbered film badges. Posted above the racks is a class roster indicating the film badge assigned to each student. Records of radiation exposures are made for all personnel exposed to radiation at the School. These records are kept on permanent file in the Radiation Dosimetry Section, and at the conclusion of each class the student's organization receives a copy if his dose exceeds 20 mrem.

   b. No smoking, drinking, or eating is permitted at any time in the presence of radioactive materials. Areas in the laboratories in which these safety precautions are enforced are the scaler laboratory (LAB 9), laboratory 4 & 5, Bldg 5218, and the alpha monitoring area.

c. Hands will be washed prior to each departure from the laboratory when radioactive emitters have been handled. Lavatory facilities are provided for this purpose.

d. Radioactive materials used for the calibration of radiac instruments will not be handled or tampered with in any way by unauthorized personnel.

DB010

STRUCTURE OF MATTER

DB010, STRUCTURE OF MATTER

I. References: Chapters 1 and 2 attached; ST 3-155, para 1.1-1.5.

II. Lesson Objectives and Notes:

A. Concept of atoms including protons, electrons, and neutrons.

B. Use of the A and Z number notation.

C. Concept of isotopes.

Notes:

III. Handouts: None

IV. Problems: None

V. Solutions: None

CHAPTER 1

STRUCTURE OF MATTER

1.1. GENERAL

In order to understand nuclear radiation, one must acquire a knowledge of the structure of matter, particularly the structure of the atom. Nuclear radiation comes from within matter as a spontaneous emission; specifically, it comes from the nucleus of the atom. This chapter provides a brief discussion of the structure of the atom as a background for studying the nature of radiation.

1.2. ELEMENTS AND COMPOUNDS

a. The following definitions dealing with the structure of matter are necessary:

(1) Elements are pure substances which cannot be broken down into simpler substances by chemical reactions. The smallest subdivision of the element which maintains the properties of the element is the atom.

(2) Compounds are substances (consisting of two or more elements) which may be broken down into simpler substances by chemical reactions; and, likewise, may be formed from simpler substances. The new substances formed do not exhibit the characteristics of the original substance. For example, sugar is a compound which can be broken down into the elements carbon, hydrogen, and oxygen. The smallest subdivision of the compound which still retains its properties is the molecule, which is a group of two or more atoms tightly held together.

b. The distinction between an element and a compound is made on the basis of chemical reactions. Means of producing chemical reactions include such procedures as heating, applying pressure, using a substance which promotes reaction (catalyst), electrolysis, or other change. If large numbers of reproducible experiments on some pure isolated substance show that none of these means is capable of breaking the substance down into still other substances, then the substance is said to be an element. There are 92 naturally occurring elements and in recent times 11 additional elements have been produced artificially in laboratories. From these 103 elements, it is possible to produce by chemical reaction all the compounds known (as well as many that are as yet unknown). For example, water is made up of the elements hydrogen and oxygen. When two atoms of hydrogen combine with one atom of oxygen, they form one molecule of the compound water.

c. It is exceedingly difficult to visualize the fantastically small size of atoms. For example, in one grain of ordinary table salt, there are approximately 1,300,000,000,000,000,000 atoms, half of which are sodium atoms and half of which are chlorine atoms. Each atom has a diameter of about 0.00000001 centimeter.

d. Each element has a different name and is represented by a symbol, which is simply a shorthand notation. For example, the element hydrogen is given the symbol "H"; the symbol for the element helium is "He." In general, these symbols are chosen as the first letter or first two letters of the element name, although to avoid duplication it may be necessary to use the first letter and a letter other than the second. Also, some of the symbols appear illogical because they are based on the old Latin names for the elements, such as "Na" for sodium and "Au" for gold. The great advantage of the element symbols is that they enable one to represent chemical reactions and chemical compounds in an abbreviated fashion; for example, the statement that a molecule of water is composed of two atoms of hydrogen and one atom of oxygen may be abbreviated by saying that the formula for water is "H_2O."

1.3. ATOMIC STRUCTURE

a. In spite of their extremely small size, atoms are built up from still smaller particles. There are three such particles, the electron, the proton, and the neutron. The many different kinds of atoms are all produced by combining these three particles in different numbers.

b. Although atoms from one element differ from those of another, all atoms have the same general type of structure and are often described by comparing them to our solar system. (Although we now know this is not strictly correct, its features give a good explanation of the simple phenomena which will be considered in this text.) The nucleus is the center of the atom, just as the sun is the center of our solar system. The nucleus has a positive electrical charge and is composed of one or more protons and neutrons. Moving at great speed around the nucleus in orbits, much as planets move about the sun, are a number of particles called electrons. The electrons have a negative charge. This structure is illustrated in figure 1.3a.

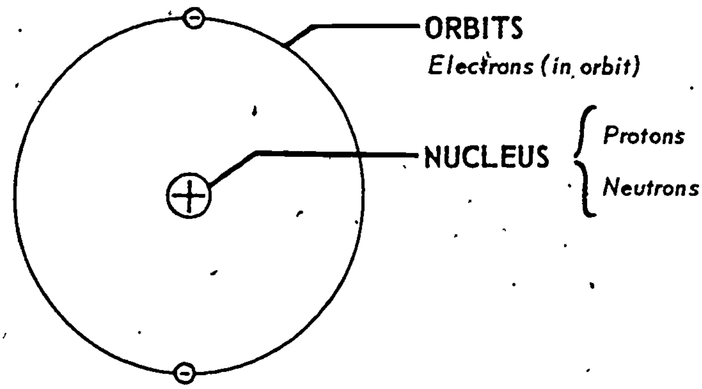


Figure 1.3a. Structure of an atom.

c. The electrons are not distributed at random about the nucleus, but exist in arrangements that follow definite laws. As the atom becomes more complex the electrons are found in several orbits or shells of different sizes. No more than two electrons may be present in the first shell, no matter which atom is under consideration. If an atom has more than two electrons, the electrons in excess of two will lie in shells past the first one. The shells are normally designated by capital letters, the first shell being denoted by K, the second by L, the third by M, and so on (fig. 1.3b). In the more complex atoms, like those of radium and uranium, there are as many as seven electron shells surrounding the nucleus of the atom.

d. The nucleus contains almost all of the mass of the atom, yet the diameter of the atom is roughly 10,000 times the diameter of the nucleus. The atom, therefore, is composed mostly of empty space.

e. One may very well wonder what holds the atom together. It is well known that unlike electrical charges attract one another, whereas like electrical charges repel one another. Since the electrons have a negative charge and the nucleus has a positive charge, there is a force of attraction between them. What, then, keeps the electron from being pulled into the nucleus? The electrons are traveling at great speeds in orbits about the nucleus, and, as a result, there is a centrifugal force tending to throw the electron away from the nucleus. The balance

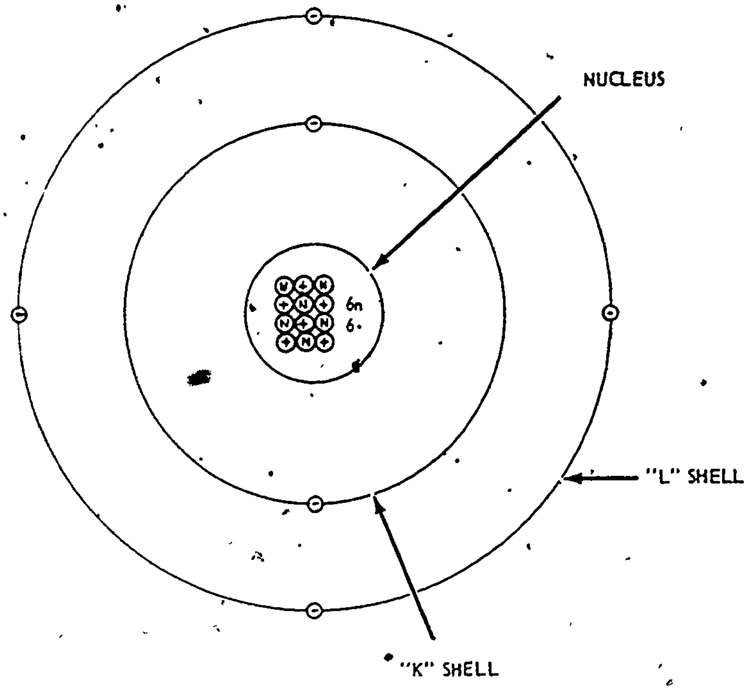


Figure 1.3b. Atom structure showing shell designations. (Structure of a carbon atom showing nucleus containing 6 protons and 6 neutrons surrounded by 2 electrons in the first, or "K," shell and 4 electrons in the "L" shell.)

between the attractive electrical force and the centrifugal force keeps the electrons in their orbits.

f. Let us consider two properties of each of the three kinds of particles of an atom: their <u>charge</u> and their <u>mass</u>. The term "<u>charge</u>" refers to their electrical charge. The magnitude of the electrical charge on an electron has been chosen as one unit of charge. The term "<u>mass</u>" refers to a measure of the quantity of matter and <u>atomic mass</u> is the measure of the quantity of matter in an atom. Because atoms are so very small, it would be exceedingly inconvenient to give their masses in terms of pounds, ounces, or even grams. A different system has been arbitrarily set up. It is called the <u>atomic mass unit</u> (amu) system. One atomic mass unit is a relative unit defined by arbitrarily assigning to the atom of ordinary carbon a mass of 12 amu. On this

scale the mass of the proton is approximately 1 atomic mass unit and the other particles may be compared with it as a standard.

(1) The electron is a negatively charged particle (charge of -1) and has a mass of approximately 1/1845 atomic mass unit. It is by far the lightest of the three basic particles.

(2) The proton has a mass of approximately 1 atomic mass unit and has a charge of +1.

(3) The neutron has a mass only slightly larger than that of a proton. For the purposes of this text, it may be said that it has a mass of 1 atomic mass unit. (Its mass may be stated as 1^+ to indicate that it is slightly more than that of the proton.) The neutron has no electrical charge (neutral). Since the nucleus of an atom has only protons and neutrons in it, it has a positive electrical charge and the magnitude of this charge is the same as the number of protons in the nucleus. The properties of these particles are summarized in table 1.1.

Table 1.1. Properties of Atomic Particles

Particle	Charge	Mass (amu)		Location within the atom
		Exact	Approximate	
Electron	-1	0.000549	$\frac{1}{1845}$	Orbits outside nucleus
Proton	+1	1.007277	1	Nucleus
Neutron	0	1.008665	1+	Nucleus

g. We know from everyday experience that the objects around us are electrically neutral. If this were not so, we would receive enormous electrical shocks from everything we touch. This must mean that every atom in the things around us is electrically neutral. The only way this is possible is for the atom to have the same number of electrons and protons, thus creating a balance between the positive and negative charges. Therefore, a statement of the number of protons in an atom is also a statement of the number of electrons.

h. What holds the nucleus together? The only charged particles in it are protons, which ought to repel each other. This phenomenon is being investigated with great interest by physicists. It is known that there is some force acting to hold the nucleus together which is unknown in connection with any other physical phenomenon. If, for example, two

protons were brought slowly together, the force of repulsion due to their having like charges would become stronger and stronger until they were extremely close together, when suddenly the attractive force acting on nuclear particles would take over and the two protons would be brought strongly together. At present, the nature of this attractive force remains a mystery.

i. Figure 1.3c shows some examples, selected at random, of atomic structures to illustrate that the atoms of all elements are made up from different combinations of the same three basic particles.

1.4. THE A AND Z NUMBER SYSTEM

a. A shorthand notation has been developed which quickly indicates the exact structure of any atom. The notation is as follows:

$^{A}_{Z}X$, in which

X is a general representation of any element symbol (in each case the appropriate element symbol would be used)

Z = the number of protons in the nucleus

A = the number of protons and neutrons in the nucleus

b. Since the Z number is equal to the number of protons in the nucleus, it is also equal to the number of electrons outside the nucleus in the normal neutral atom. The Z number is usually called the atomic number. The significance of this term is that all the elements may be arranged in a sequence according to certain measurable chemical and physical properties. This sequence corresponds to an increasing number of protons, so that the position of the element in this sequence (its "atomic number") is the same as the number of protons.

c. The chemical properties of an atom depend on the number of electrons it possesses; only electrons take part in chemical reactions; the nucleus is unaffected. Since the number of protons equals the number of electrons, it is possible to say that the chemical properties depend on the number of protons. Thus, the number of protons (Z number, or atomic number) identifies which element is represented by a particular atomic structure. For example, all atoms of the chemical element sodium have 11 protons. Therefore, writing a Z number of 11 is the same as writing that the element is sodium or that the element symbol is Na. Thus, the Z number effectively tells what the element is, and, conversely, the element symbol tells what the Z number is, although it may be necessary to go to a table to determine one from the other.

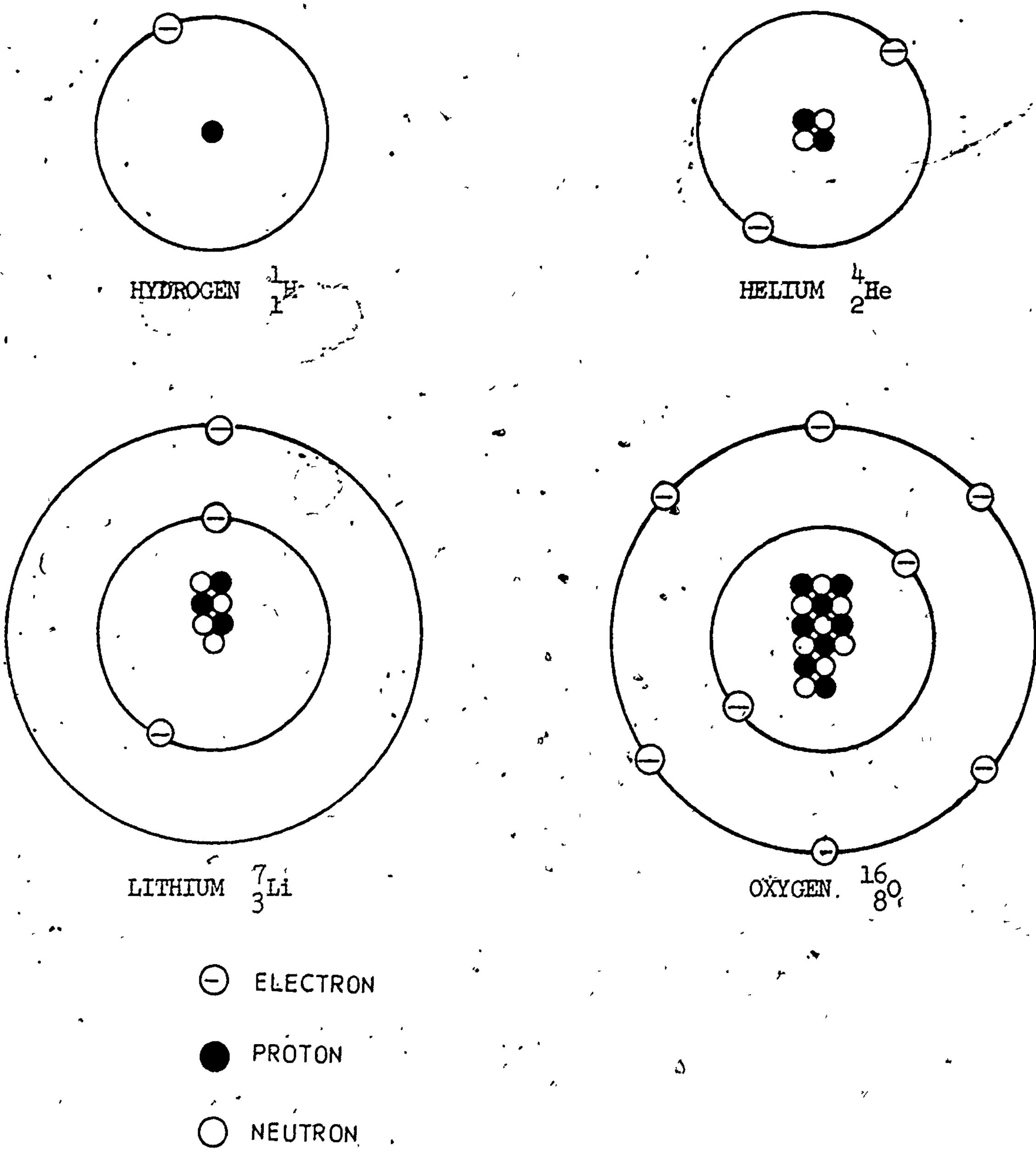


Figure 1.3c. Examples of atomic structures.

d. The A number is often called the nucleon number. A nucleon is defined as any particle found in the nucleus; the term simply provides a convenient way of referring to both protons and neutrons. Since the A number represents the sum of the protons and neutrons, it is equal to the number of nucleons. The A number is also called the atomic mass number. Since the mass of both the proton and the neutron is approximately one, the sum of protons and neutrons gives the mass of the nucleus (and the atom, because the masses of the electrons are nearly zero); hence, the term "atomic mass number."

e. The number of neutrons in the atom is given by the difference between the A and Z numbers:

$$A - Z = \text{number of neutrons}$$

f. An example of the A and Z number terminology and the deductions that can be made from it are indicated below.

EXAMPLE:

$${}^{35}_{17}Cl$$

Number of protons in this atom: 17

Number of electrons in this atom: 17

Number of neutrons and protons (nucleons) in this atom: 35

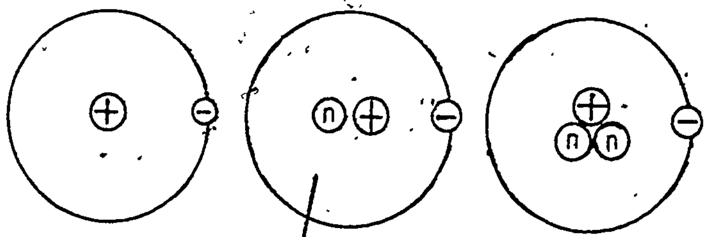
Number of neutrons in this atom: 35 - 17 = 18

Element of which this is an atom: Cl (chlorine)

1.5. ISOTOPES

a. It is possible for different atoms of the same element to have somewhat different nuclear structures. This difference must not be in the number of protons, since it has already been stated that the element is determined by the number of protons in the nuclei of the atoms of the substance. The difference is in the number of neutrons. For example, there are three known forms of the element hydrogen (three isotopes of hydrogen)--two are found in nature and one is manmade. The structures of these three atomic forms of hydrogen are illustrated in figure 1.5.

b. Figure 1.5 should indicate to the reader the criterion for isotopes: Two (or more) atoms are isotopes if they have the same number of protons but different numbers of neutrons. Another way of stating the same definition is: Two (or more) atoms are isotopes if they have the same Z number but different A numbers.



Number of protons	1	1	1
Element	*Hydrogen-1*	*Hydrogen-2 (Deuterium)*	*Hydrogen-3 (Tritium)*
Element symbol	*H*	*H*	*H*
Number of neutrons	0	1	2
Number of nucleons	1	2	3
Complete symbol	$^{1}_{1}H$	$^{2}_{1}H$	$^{3}_{1}H$

Figure 1.5. The isotopes of hydrogen.

c. Since two atomic forms which are isotopic have the same number of protons, they have the same number of electrons; therefore, they will behave the same chemically. The differences in behavior are in physical properties; for example, hydrogen-1 ($^{1}_{1}H$) and hydrogen-2 ($^{2}_{1}H$) are not radioactive, yet hydrogen-3 ($^{3}_{1}H$) is radioactive.

d. Because the three isotopes of hydrogen have become very important in nuclear work, each has been given a separate name for simplicity in speaking. These names are:

hydrogen-1	(common) hydrogen
hydrogen-2	deuterium
hydrogen-3	tritium

Hydrogen is the only element for which a special nomenclature has been devised for the different isotopes. For all other elements, the different isotopes are spoken of by the more basic nomenclature; for example, $^{3}_{2}He$ and $^{4}_{2}He$ are referred to as helium-3 and helium-4, respectively.

e. Isotopes always occur as two or more for any given element. It is proper to speak of isotopes as isotopes of the element which they represent; thus, helium-3 and helium-4 may be spoken of as the isotopes of helium.

f. Through custom, a rather loose terminology has become accepted in which all atomic species are collectively referred to as isotopes. For example, one might read that "two radioactive isotopes commonly used to calibrate radiac instruments are cobalt-60 and cesium-137." This terminology is actually in error, since these two structures are not isotopes of one another. However, such usage is quite common. A more accurate way of speaking employs the term "nuclide." A nuclide is any nuclear species. Thus, the statement, "Two radioactive nuclides commonly used to calibrate radiac instruments are cobalt-60 and cesium-137," contains no error. The more accurate terms "isotope" and "nuclide" will be used in this text.

1.6. MASS-ENERGY EQUIVALENCE

For centuries man believed in twin laws of conservation, the conservation of energy, which states energy cannot be created nor destroyed, and the conservation of matter, which states that mass cannot be created nor destroyed. Today we know that these laws are not valid when they are considered individually. In 1905 Einstein discovered a new law often referred to as conservation of mass-energy which states that mass and energy cannot be created or destroyed but can be converted from one form to the other. Thus, if some mass disappears, an equivalent amount of energy will appear. This equivalence is given by the equation:

$$E = mc^2$$

where:

E = the energy in ergs

m = rest mass in grams

c = speed of light $\cong 3 \times 10^{10}$ cm/sec

This equation states that any body having a rest mass (m) also has a total energy (E) associated with it given by the product of its mass multiplied by the square of the speed of light. On the basis of this concept, a 1-gram mass of an element is equivalent to an energy of 9×10^{20} ergs:

$$E = mc^2$$

$$E = (1)(3 \times 10^{10})^2 \text{ ergs}$$

$$E = 9 \times 10^{20} \text{ ergs}$$

and since 1 erg = 2.78×10^{-14} kilowatt-hours

$$E = (9 \times 10^{20}) \times (2.78 \times 10^{-14})$$

$$\therefore E = 25{,}000{,}000 \text{ kilowatt hours}$$

This amount of energy, in thermal units, is equal to approximately 85 billion BTU or 21 trillion calories of heat energy.

1.7. MASS DEFECT AND BINDING ENERGY

One might believe that the mass of an atom could be determined by counting the number of neutrons, protons, and electrons, and simply adding the masses of these basic particles. Let's experiment with $^{19}_{9}F$, a common isotope of fluorine. This isotope has 9 protons, 9 electrons, and 10 neutrons.

nine protons (9 x 1.007277)	=	9.065493 amu
nine electons (9 x 0.000549)	=	0.004941 amu
ten neutrons (10 x 1.008665)	=	10.086650 amu
Total		19.157084 amu

19.157084 amu represents the sum of the masses of the basic particles in the $^{19}_{9}F$ atom. From a table of atomic masses, such as may be found in Ordnance Pam 25, we find that the known mass of this nuclide is 18.998405 amu. The difference between the known mass and the sum of the masses of the particles is 0.158679 amu. It appears that the $^{19}_{9}F$ atom is missing this amount of mass. Careful study has shown that when an atom is formed from the basic particles a certain amount of mass disappears and changes to energy in accordance with Einstein's $E = mc^2$. This mass that is lost is called the <u>mass defect</u>. Every different atom has a different mass defect. The energy that is released when an atom is formed from the basic particles is proportional to the mass defect and is called the <u>binding energy</u> of the atom. Because binding energies for particular atoms are much smaller than energies we are familiar with in everyday life, a small unit of energy must be used to describe them. An <u>electron volt</u> (ev) is a useful small unit of energy commonly used in nuclear physics. To define an electron volt, consider two parallel charged plates connected by a 1-volt battery. One plate will be attached to the positive pole of the battery and will therefore have a positive charge on it; the other plate will be attached to the negative pole and have a negative charge on it. If an electron is released near the surface of the negative plate, it will be attracted to the positive plate since an electron is negatively charged. The amount of kinetic energy (speed) that it will possess when it hits the positive plate will be equal to 1 electron volt. In the nuclear events discussed in the later chapters of this text, units of <u>millions of electron volts</u> (Mev) are used.

CHAPTER 2

NATURE OF RADIOACTIVITY

2.1. GENERAL

An understanding of the military aspects of radioactivity and radiation hazards requires some knowledge of the nature of radioactivity. This chapter is designed to give the reader that knowledge. It begins with a brief historical background, then discusses the observed properties of each type of nuclear radiation and how we may represent these radioactive processes in nuclear reaction equations. A brief discussion is given concerning the origin of the different types of radiation in the nucleus. Several examples of artificially induced reactions are given, including two especially important ones--fission and fusion.

2.2. HISTORICAL BACKGROUND

a. Most persons first heard of nuclear radiation when the first atomic bombs were dropped on Japan in 1945. Therefore, it is commonly believed that nuclear radiation is something very new to man's experience. This is not true; actually, nuclear radiation was discovered in 1896 by a French scientist named Henri Becquerel. Becquerel experimented with fluorescent crystals which when struck by ordinary white light gave off in return light of some color, such as pink or green. He discovered, he believed, that certain crystals when struck by light gave off some sort of very penetrating rays, different from light rays, capable of penetrating thin sheets of paper or metal.

b. In the course of trying to determine the properties of these substances that gave off the penetrating rays, Becquerel regularly performed the following experiment: He wrapped a photographic plate with a piece of paper so that light could not get to the plate and expose it; then, on top of the paper he put a small pile of crystals of a salt of uranium (impure). He then placed this apparatus outdoors in the sun all day. At the end of the day, he brought the entire set of materials indoors and developed the photographic plate. He always found a black spot on the plate under the crystals. This led him to the belief that when these crystals were exposed to light they gave off some previously unknown kind of radiation which was capable of penetrating the paper and exposing the film.

c. Becquerel's experiments with these crystals might have proved no more informative than this if it had not been for a lucky accident. One day when he was preparing to set his standard experiment in the sun, the sun failed to come out; he therefore placed the entire apparatus in his top desk drawer to await a sunny day. As it happened the sun failed to

shine for several days; on the first day that it did come out he was going to place the apparatus in the sun, but, for some unknown reason, he developed the plate directly instead. It turned out that the plate was blackened under the crystals in spite of the fact that the entire apparatus had been in darkness for several days. This forced Becquerel to revise his original conclusion about these crystals. Apparently light was not necessary to cause these crystals to give off the penetrating rays; rather, these rays were given off spontaneously from within the material itself without the assistance of any outside agency. We now know that these rays come from the nuclei of the atoms of the material; for this reason, they are called nuclear radiation.

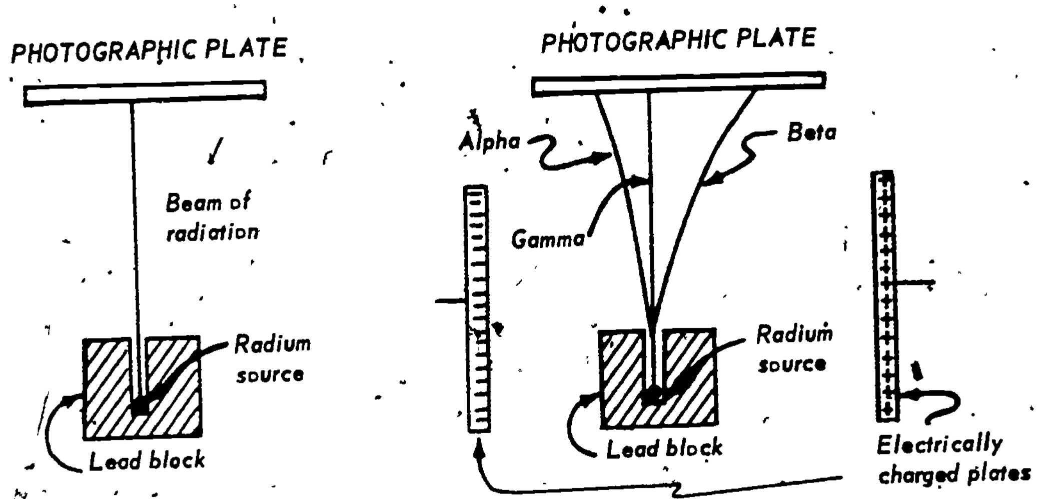
d. Further research by Becquerel and others demonstrated that the emission of the strange new penetrating rays by these substances (called radioactive substances) was unaffected in any way by heat, light, pressure, chemicals, mechanical force, or any other means known then. Much experimental work was done in the years following Becquerel's discovery in an attempt to find out what sort of phenomenon these rays were. The following paragraph describes one of these early experiments and the conclusions drawn from it.

2.3. TYPES OF RADIATION

a. At first it was believed that the rays emitted by radioactive substances were composed of only one kind, the nature of which was unknown. An early experiment which proved that this belief was untrue is illustrated in figure 2.3. In the experiment depicted in part (1) of the figure, a sample of radium (one of the few radioactive substances known at the time) was placed at the bottom of a cylindrical hole drilled in a piece of lead (the figure shows a cross section of the lead block). As will be explained in DF060 and DF100, lead has the ability to absorb radiation very effectively, so that very little of the radiation escaped around the sides of the block. Therefore, there was essentially a straight "beam" of radiation directly out the hole. A photographic plate was placed across the path of the radiation and upon development showed one dark spot in the center of the plate. This confirmed the notion that only one thing was present in this beam of radiation.

b. In the experiment depicted in part (2) of figure 2.3, the beam of radiation was subjected to a strong electrical field. A photographic plate was placed in the beam of the radiation. However, when the plate was developed it was found that there were three black spots on the plate, indicating that the electric field had separated the beam of radiation into three kinds of radiation, as illustrated in the figure. Since no one knew what these three kinds of radiation were at the time, they were arbitrarily named by the first three letters of the Greek alphabet--

alpha (α) for the kind attracted to the negative side of the field, beta (β) for the kind attracted to the positive side of the field, and gamma (γ) for the kind not attracted to either side.



(1) Experiment without electric field.

(2) Experiment with electric field.

Figure 2.3. Path of emanations from a radium source: (1) without electric field; (2) with electric field.

c. Several conclusions can be reached as a result of the experiment illustrated in figure 2.3 beyond the basic one that three kinds of radiation were coming from the radioactive substance. This experiment indicates that: (1) alpha radiation, which was attracted to the negative plate, has a positive electrical charge; (2) beta radiation, which was attracted to the positive plate, has a negative charge; and (3) gamma radiation, which was undeflected by the electric field, has no charge (electrically neutral).

2.4. ORIGIN OF RADIATION IN THE NUCLEUS

There has always been a bombardment of the earth by one type of radiation--cosmic radiation. Also, many of the machines of modern

science generate radiation hazards. These hazards, however, are normally small and closely controlled in comparison to the military picture which introduces the serious matter of high dose rates at the scene of a nuclear weapon explosion, or the radioactive hazards of radiological agents.

a. Nuclear Energy. An understanding of nuclear radiation requires some insight into the origin of radiation from the nucleus. Certain nuclear structures have too much energy and are constantly attempting to reduce their energy content by releasing energy. They do this by emitting one or more of the types of nuclear radiation--alpha, beta, or gamma. (Types of nuclear radiation are discussed in para. 2.5). Stated another way, these unstable nuclei seek to reach a more stable state by releasing excess energy as nuclear radiation. This leads us to the following definition(for the purposes of this text): A radioactive nuclide (radionuclide) is a nuclide whose atoms have unstable nuclei which attempt to reach a more stable (less energetic) state by releasing excess energy in the form of nuclear radiation. When the nuclear radiation thus emitted is in the form of a charged particle, the disintegrating atom becomes an atom of a different element. For example, when a radium atom disintegrates, emitting radiation, it becomes an atom of radon. The resulting atom may also be unstable and further disintegrate to an atom of still another element. This may continue through an entire series of elements (ST 3-155, Ch 3). The result of this process is a family of naturally occurring radioactive elements. Careful research has developed the fact that four families of natural radioactive elements exist, deriving from uranium, thorium, actinium, and neptunium. The first three decompose through intermediate steps to form different isotopes of lead. Thus, natural lead is a mixture of the three end products of radioactive family decay, plus a fourth nuclide, ^{204}Pb. The fourth radioactive family, beginning with the newly prepared element neptunium, has an isotope of bismuth as its end product. Neptunium is no longer found in nature, and the discovery of this fourth radioactive family came as a result of man's work with nuclear weapons. Neptunium is an intermediate product of the atomic pile.

b. Nuclear Forces. To understand radioactivity further, a brief discussion of the interaction of forces in the nucleus is desirable. As has been pointed out, it appears peculiar that the nucleus is held together at all; since like charges repel, the electrical (coulomb) forces between protons apparently should cause the nucleus to fly apart. However, the repulsive coulomb forces between protons are overcome by other forces within the nucleus. These forces are of very short range, acting only between nucleons close to each other. The balance between

the attracting nuclear forces and repelling coulomb forces is the important factor in nuclear stability. In stable atoms the attraction forces are adequate to overcome the repelling coulomb forces, and the nucleus stays together. In unstable atoms this balance is a delicate one. The nucleus will hold together only so long as the attracting nuclear forces hold the upper hand. If the repelling coulomb forces should overcome these strong attraction nuclear forces, part of the nucleus may break off and escape. In other cases rearrangements within the nucleus which lead to more stable configurations may take place without the loss of particles. Nuclides whose nuclei undergo this process are said to be unstable or radioactive.

c. Gamma. Nuclei may release gamma radiation as a means of decreasing their energy content. Since gamma radiation consists of pure energy, its emission leaves the nucleus with less energy in the amount of energy of the gamma ray. This emission of gamma radiation accompanies a rearrangement of nuclear particles; it does not involve a change in the number or kind of nucleons in the nucleus.

d. Alpha. The configuration of the helium nucleus is extremely stable; therefore, it is reasonable that radioactive nuclei may eject this configuration. The off-going alpha particle has considerable kinetic energy; that is, energy due to motion. The energy of the nucleus which emits the alpha particle is decreased by the amount of kinetic energy which it imparted to the particle.

e. Beta. It is not so easy to visualize how a beta particle can be emitted from a nucleus. The statement that beta radiation comes from the nucleus but that there are no electrons in the nucleus appears to be a contradiction. The accepted explanation for this result is that it is possible for a neutron to split into a proton and an electron.[1] If this splitting occurs, the electron is then ejected from the nucleus with great speed; that is, great kinetic energy, which reduces the energy level of the nucleus. This process is illustrated in figure 2.4.

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[1]Actually, there is a third particle, the anti-neutrino, also involved. The anti-neutrino is a tiny particle much smaller than the electron. The neutron breaks down into a proton, electron, and anti-neutrino. The latter two are ejected from the nucleus. No further consideration will be given to the anti-neutrino in this text.

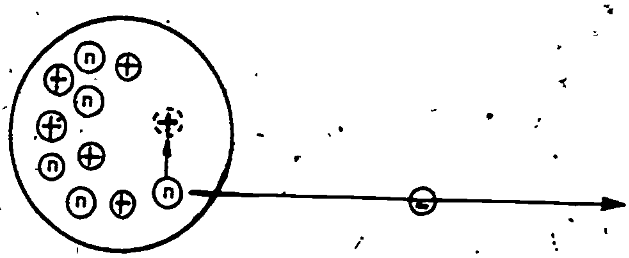


Figure 2.4. Beta emission.

2.5. NATURE OF RADIATION

a. General: The natural decay of the radioactive families mentioned above results in three types of nuclear radiation: alpha (α); beta (β), and gamma (γ). These three types of nuclear radiation are also called ionizing radiation because of their ability to ionize atoms and molecules of the matter through which thev pass. (A detailed discussion of ionization[2] may be found in ST 3-155, Ch 4. Each of the 3 types of radiation -- alpha, beta, and gamma--will be discussed below with regard primarily to three properties: their charge, their mass, and an overall descriptive characteristic.

b. Alpha. It has already been stated that alpha radiation has a positive electrical charge; more specifically, alpha radiation consists of fast-moving stable particles with a charge of +2 on each particle. Each particle is composed of two neutrons and two protons ejected as a

[2]For the purpose of this text, ionization is the removal of electron(s) from a neutral atom, and ion pairs are the result of this process.

single entity from a disintegrating nucleus and has a mass of 4 atomic mass units (amu). This alpha particle has the same composition as the nucleus of the helium-4 (^4_2He) atom. The helium-4 atom has two protons and two neutrons in the nucleus and two electrons outside the nucleus to balance the charge. If the electrons were stripped away, the resulting nucleus would be identical with an alpha particle except that an alpha particle is normally traveling at speeds approximately one-tenth the speed of light. (Its speed is normally on the order of 2,000 to 20,000 miles per second.) In fact, as the alpha particle slows down in its passage through matter, it annexes two electrons and becomes a neutral helium-4 atom. The alpha particles are about 7,500 times as heavy as an electron and 4 times as heavy as a hydrogen atom. This configuration of two protons and two neutrons is extremely stable as nuclear structures go; this helps to explain why this structure should be emitted from a nucleus in preference to other combinations of nucleons.

(1) Alpha particles are characterized by their high ionizing capability. A means of comparing the ionizing ability of different kinds of ionizing radiation is by comparing their energies and the number of ion pairs produced per unit length of travel as each passes through the same medium. (Ionization and ion pairs are discussed in chapter 4.) For example, an alpha particle with an energy of 1 Mev (million electron volts)[3] will create about 10,000 ion pairs per centimeter of path as it passes through air. A beta particle (the radiation with the next highest ionizing capability) with the same energy traveling along the same path will create about 33 ion pairs per centimeter of travel. Thus, the ionizing ability of the alpha particle is about 300 times as great as that of the next most highly ionizing type of radiation.

(2) Because of this high ionizing ability, the alpha particle dissipates its energy quickly in any medium. For example, the range of alpha particles varies from a few thousandths of a centimeter in solid materials such as photographic film up to a few centimeters in gaseous materials such as air. To penetrate the protective layer of the skin, alpha particles with energies of 7.5 Mev (million electron volts) or more would

[3]Energies of radiation are expressed in units of electron volts. The electron volt is the energy (speed) a unit charged particle acquires when it falls through a potential of one volt; it is equivalent to 1.6021×10^{-12} ergs (par. 1.7).

be required. Because of this short range, the danger to the body from external alpha emitters is in most cases negligible. Alpha emitters, however, may be extremely injurious if they gain admittance to the body. In this case, because of their high ionizing ability, the alpha particles will expend their energy in a single group of cells and cause a very high degree of localized tissue damage in the vicinity of the alpha emitter. Under similar circumstances, alpha emitters are considered to present an internal hazard 20 times as great as beta or gamma emitters (table 2.1).

Table 2.1. Relative Ionizing Power

Radiation	Relative ionizing power
Alpha particle	10,000
Beta particle	100
Gamma ray	1

c. Beta. Beta radiation consists of very high velocity electrons which have been ejected from a disintegrating nucleus. These beta particles are also ionizing radiation. The experiment on the separation of radiation indicated that beta radiation had a negative electrical charge. Beta radiation was shown to be a stream of electrons traveling at speeds about nine-tenths the speed of light. (Its speed is normally on the order of 100,000 to 180,000 miles per second.) This means that the mass of the beta particle is 1/1845 atomic mass unit and that its charge is -1. The negatively charged beta particle will ionize matter as it passes through it, thus losing speed (energy) until it is undistinguishable from a free electron; in other words, it is identical with the electrons that orbit about the nucleus of atoms except for its speed and origin. Note that beta particles originate in the nucleus of the atom.

(1) Because of its higher speed and smaller mass and charge in relation to an alpha particle, the beta particle exerts less force for a shorter period of time on the atoms of the material through which it passes. Thus, its ionizing ability is less and its range greater. (The range of a 1-Mev beta particle in standard air is about 10 feet.)

(2) These factors normally make the beta emitters a less serious internal hazard than the alpha emitter. However, since the beta particle can penetrate the skin and damage living cells, the beta emitter can create an external hazard.

d. Gamma. Gamma radiation does not consist of particles, it has no electrical charge, and appropriate experiments have proven it to have no mass. The reader may well question the nature and existence of something that has neither charge nor mass. What is gamma radiation? It is pure energy traveling through space at the speed of light. It is one example of a general type of radiation called electromagnetic radiation. It is a form of electromagnetic radiation differing only in frequency (energy) and source from more commonly known forms such as X-rays, infrared, visible light, ultraviolet, and radio waves. Gamma radiation is generally of higher frequency (energy) than the above types and is generated by a stabilizing nucleus. The reader is familiar with some other types of electromagnetic radiation; namely, radio waves, light waves, and X-rays. Consider radio waves. The human senses cannot detect radio waves; we cannot see, hear, taste, feel, or smell them. The only way we can detect them and make them audible is by the use of an instrument for detecting radio waves; namely, a radio. Similar statements are true about gamma radiation; the human senses are not capable of detecting it; we must have a special instrument for detecting it, a type of instrument called a radiac instrument (DF110). The reader may wonder why radio waves do not hurt him, whereas gamma rays will cause injury. The difference lies in the amount of energy possessed by these two different kinds of electromagnetic radiation. Gamma radiation possesses much more energy than radio waves and therefore is capable of damaging living organisms. A type of radiation much more akin to gamma radiation is X-radiation. As with other types of electromagnetic radiation, it is not possible to detect X-rays by use of the senses. Also, we know from experience that these rays are very penetrating, since they are used to photograph the inside of the body (whereas light is capable only of making a photograph of the outside of the body). X-rays have about the same energy as gamma rays have. The distinction between them is their origin. Gamma rays come from within the nucleus; X-rays do not. Gamma radiation travels in a straight line and with the speed of light (186,000 miles per second). Many experimental results have been obtained using gamma radiation and are satisfactorily explained on the basis that gamma radiation is a wave that transmits energy through space. However, if certain other experiments are performed, such as those involving the interaction between gamma radiation and atoms, the results cannot be satisfactorily explained by considering the radiation to be a wave. Rather, the radiation behaves as though it consisted of a stream of tiny packets of energy, each packet having zero mass but being able to produce effects as though it were a particle. Each of these little packets of energy is called a photon of radiation. This dual wave-particle nature of electromagnetic radiation is difficult to grasp and believe, but no other satisfactory explanation is available for the various possible interactions of electromagnetic radiations with matter and

with electric and magnetic fields. Thus, gamma rays may be said to act with this dual wave-particle nature and to produce results consistent with the theory. The importance of the particulate nature of gamma radiation (photon nature) will become clearer in the discussion of ionization by gamma radiation.

2.6. WRITING NUCLEAR REACTION EQUATIONS

a. General. Just as the chemist has a shorthand way of writing down what takes place in chemical reactions, the physicist has a shorthand way of writing nuclear reactions in the form of equations. This system makes use of the A and Z number notation explained in chapter 1. The logical development of the method of writing nuclear reaction equations is illustrated below by a study of the three modes of radioactive decay already discussed.

b. Alpha Emission.

(1) To see what results from alpha emission, consider the isotope uranium-238 ($^{238}_{92}U$). This is a naturally occurring nuclide which is radioactive and an alpha emitter. Since two protons and two neutrons are subtracted from the uranium nucleus, a new substance, an isotope of thorium, is formed. This is illustrated in figure 2.6a.

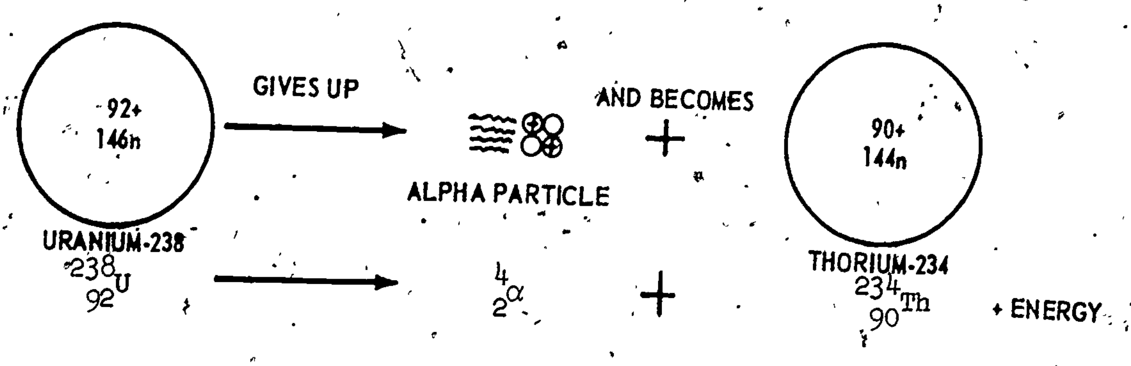


Figure 2.6a. Alpha emission from uranium-238.

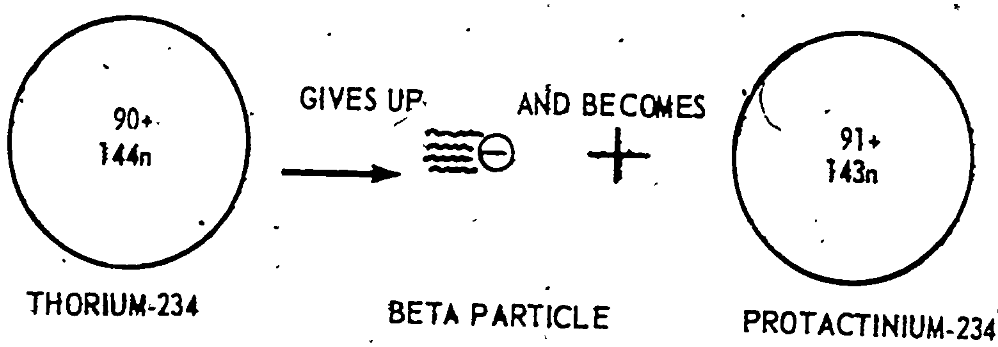
(2) The process illustrated in figure 2.6a can be indicated in another way by using the A and Z number system. To do this we must have an appropriate symbol for the alpha particle. The symbol used is $^4_2\alpha$ or ^4_2He. (Although ^4_2He is properly the symbol for the whole helium-4 atom, it is very often used to represent the alpha particle.) Using this notation, we may write the equation for the emission of an alpha particle by a uranium-238 atom as follows:

$$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th + Q\ (\text{energy})$$

This equation says that an atom of uranium-239 forms an alpha particle and an atom of thorium-234. One additional symbol which appears here is the letter Q. This Q stands for energy. An energy term is involved in every nuclear reaction. In this case, the energy given off is simply the energy possessed by the alpha particle (plus a small amount of energy for the recoil of the nucleus). Note that the sum of all the A numbers on the left side of the equation equals the sum of all the A numbers on the right side (238 = 4 + 234); also, the sum of the Z numbers on the left is the same as the sum of the Z numbers on the right (92 = 2 + 90). The student should think through the reason for this from what is taking place in the actual physical reaction. This rule about equality of A and Z number sums on both sides of an equation will be shown to be valid in other nuclear reactions; in fact, it is a general rule which may be used as a <u>mechanical</u> aid to balancing nuclear reactions.

c. Beta Emission.

(1) The thorium isotope that was formed in the earlier example on alpha radioactivity is a beta-emitter, causing thorium-234 to change to the element protactinium. This is illustrated in figure 2.6b. The mass number A does not change in beta decay, but the atomic number Z increases by 1, because a proton has been gained. This gain comes about when a neutron breaks down, ejecting an electron and retaining the proton.



$${}^{234}_{90}\mathrm{Th} \longrightarrow {}^{0}_{-1}e + {}^{234}_{91}\mathrm{Pa} + \text{ENERGY}$$

Figure 2.6b. Beta emission from thorium-234.

(2) In order to write a nuclear equation for the process illustrated by figure 2.6b, it is necessary to have a suitable symbol for a beta particle. For brevity, a beta particle is often represented by the symbols β^- or e^-; however, for equations we must assign A and Z numbers to the beta particle. Clearly, the basic definitions of A and Z numbers are not applicable. Therefore, an extension of the basic system is used, and the beta particle is given more or less artificial A and Z numbers, which represent the effect of a beta particle on a nuclear reaction. Because of its negative charge, the beta particle is given Z number -1; because its mass is very small it is given an A number of zero. Thus, beta may be indicated by ${}_{-1}\beta$, or ${}_{-1}e$. The emission of a beta particle by a thorium-234 nucleus may be written as follows:

$${}^{234}_{90}\mathrm{Th} \rightarrow {}^{0}_{-1}\beta + {}^{234}_{91}\mathrm{Pa} + Q$$

Note once again that the sum of the A numbers on the left equals the sum of the A numbers on the right ($234 = 0 + 234$) and the sum of the Z numbers of the left equals the sum of the Z numbers on the right ($90 = -1 + 91$).

d. Gamma Emission.

(1) Previously it was said that an unstable configuration of neutrons and protons in a nucleus is sometimes made more

stable by a rearrangement of the particles within the nucleus without the emission of a particle. Such internal rearrangements are accompanied by radioactivity in the form of pure energy. With different configurations of the nucleus the components are bound with different energies, and upon rearrangement energy is released in the form of electromagnetic waves called gamma rays. Each time one atom releases energy in this way it is said to have released a photon of gamma radiation. The photon is like a small "bundle" of energy. The significance of the photon concept is discussed more fully in ST 3-155, Ch 4. It is important to note that no change in the A and Z numbers accompanies gamma emission and the only effect upon the nucleus involved is to leave it with less energy. An example of gamma emission is illustrated in figure 2.6c.

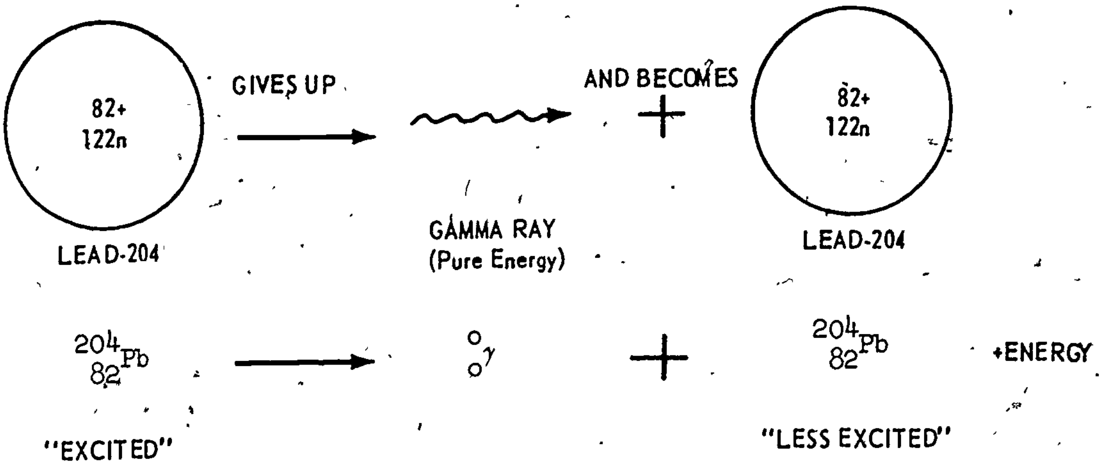


Figure 2.6c. Gamma emission from lead-204.

(2) The symbol for gamma radiation in the A and Z number system is $^{0}_{0}\gamma$, representing the fact that it has no mass and no charge. The equation corresponding to the reaction illustrated in figure 2.6c is:

$$^{204}_{82}Pb \rightarrow {}^{0}_{0}\gamma + {}^{204}_{82}Pb + Q$$

e. Summary. Table 2.2 summarizes the properties of nuclear radiation.

Table 2.2. Properties of Nuclear Radiation

Type of radiation	Symbol	Charge	Mass (amu)	Characteristic	Effect of emission on parent nucleus: Atomic no. (Z)	Effect of emission on parent nucleus: Mass no. (A)
Alpha particle	${}_{2}^{4}\alpha$; or ${}_{2}^{4}He$	+2	4	2 protons 2 neutrons (same as nucleus of He-4 atom)	Decreases 2	Decreases 4
Beta particle	${}_{-1}^{0}\beta$, or ${}_{-1}^{0}e$	-1	$\frac{1}{1845}$	High-speed electron	Increases 1	No change
Gamma ray	${}_{0}^{0}\gamma$	0	0	Form of electro-magnetic energy similar to X-rays	No change	No change
Neutron	${}_{0}^{1}n$	0	1	Neutral particle	No change	Decreases 1
Positron	${}_{+1}^{0}\beta$ or ${}_{+1}^{0}e$	+1	$\frac{1}{1845}$	High-speed, positively charged electron	Decreases 1	No change

Two general rules which are always valid in balancing nuclear equations are:

(1) The sum of the A numbers of the reactants must always equal the sum of the A numbers of the products. Mathematically, this is written: $\Sigma A_r = \Sigma A_p$.

(2) The sum of the Z numbers of the reactants must always equal the sum of the Z numbers of the products. Mathematically, this is written: $\Sigma Z_r = \Sigma Z_p$.

2.7. ARTIFICIALLY INDUCED NUCLEAR REACTIONS

a. Thus far, the entire discussion of radioactivity and nuclear processes has centered about natural radioactivity in the form of alpha, beta, and gamma radiation. However, man has learned to produce nuclear reactions artificially, thus creating new radioactive nuclides not found in nature and producing other results that are of considerable importance. Normally, artificial reactions are induced by firing a nuclear particle at a target containing the type of atoms in which the reaction is desired. The nuclear particles used as projectiles are made to move at great speed (with great energy) by the use of machines called particle accelerators. The discussion of how these machines operate is beyond the scope of this text. The particles most commonly used as projectiles are the following:

(1) Alpha particle (^4_2He).

(2) Beta particle ($^{0}_{-1}\beta$).

(3) Proton (^1_1H) ; nucleus of the hydrogen-1 atom.

(4) Neutron (^1_0n).

(5) Deuteron (^2_1H) ; nucleus of the hydrogen-2 (deuterium) atom.

b. A few typical examples are given below to indicate the general nature of artificially induced nuclear reactions.

(1) Alpha-neutron type:

$$^9_4Be + {}^4_2He \rightarrow {}^1_0n + {}^{12}_6C + Q$$

(2) Alpha-proton type:

$$^{14}_7N + {}^4_2He \rightarrow {}^1_1H + {}^{17}_8O + Q$$

(3) Neutron-gamma (radiative capture) type:

$$^1_1H + {}^1_0n \rightarrow {}^2_1H + {}^0_0\gamma + Q$$

It should be understood that in each of the reactions shown above, the particle or ray emitted, such as a neutron, proton, or gamma ray, is emitted instantaneously when the reaction takes place. For instance, in the last example above, the equation does not mean that $_1H$ is radioactive and a gamma emitter; the gamma ray shown is emitted at the instant of the reaction. The product ^2_1H in this case is stable. In

other cases, the product may be radioactive. Thus, the product nuclei may continue emitting radiation over an extended period of time.

c. Artificially induced nuclear reactions have created other types of radiation that have not been previously mentioned in this text. Two of these types, neutron and positron, are discussed briefly below:

(1) Neutron radiation consists of neutrons ejected from an excited or fissioning nucleus. Since the neutrons are uncharged, no electrostatic forces come into play with either the orbital electrons or the nuclei. Thus, for neutrons to affect matter they must enter the nucleus or come sufficiently close to it for the nuclear forces to act. The reaction of a neutron with a nucleus leaves the nucleus in an excited state, due to the added kinetic energy contributed from the neutron. This excess energy is removed by emission of particle radiation, i.e., ejection of an alpha particle. More will be said about neutron reactions in DF212.

(2) Positron radiation consists of high-velocity, positively charged particles that have been ejected from a disintegrating nucleus. This type of emission is normally associated with the fusion process. Experiments have shown that the positron is a fundamental particle (that is, it belongs in the same class as the neutron, proton, and electron) having the same mass as the electron (1/1845 atomic mass units) and a charge equal in magnitude to the electron but opposite in sign (charge of +1). The accepted explanation of its origin is that it is possible for a proton to split into a neutron and a positron.[4] When this splitting occurs, the positron is ejected from the nucleus with great speed; that is, kinetic energy. This reduces the energy level of the nucleus in the same manner as beta emission does. Throughout this text the word electron or beta will be used to denote the negative electron and the word "positron" or "beta-plus" will be used for the positive electron.

2.8. ENERGY RELEASE

a. General. Before proceeding further in the discussion of radioactivity, let us first consider the energy (Q) associated with a nuclear reaction. The energy released by a conventional reaction results from rearrangement of the atoms of the reactants; for example, the hydrogen, carbon, oxygen, and nitrogen in TNT. Such a rearrangement of atoms within a substance constitutes a chemical reaction. In a nuclear reaction the energy is produced by a redistribution or a recombination

[4]Actually, as in the case of beta emission, there is a third particle, the neutrino, also involved.

of the protons and neutrons of the atoms. Such a redistribution of nuclear particles constitutes a physical reaction. The forces between the protons and neutrons within an atomic nucleus are tremendously greater than the forces between atoms; consequently, nuclear energy is of a very much higher magnitude than conventional energy when equal masses are considered. Many nuclear processes are known, but not all are accompanied by the release of energy. The basic requirement for energy release is that the total mass of the interacting reactants be more than the mass of the resultant products. There is a definite equivalence between mass and energy as discussed in paragraph 1.6. If in a nuclear reaction there is an accompanying release of energy, that energy is definitely related to the decrease in mass. Mass change reflects the difference in the forces in various nuclei. The energy released in a nuclear reaction is derived primarily from the conversion of the binding energy that bound the nucleus together.

b. Energy Calculations. Let us consider the reaction of beryllium-9 being bombarded by an alpha particle and forming carbon-12 and a neutron and releasing energy (Q). Written symbolically the reaction is:

$$ {}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{1}_{0}n + {}^{12}_{6}C + Q $$

The total mass of the reactants is:

$$
\begin{array}{lcr}
{}^{9}_{4}Be & - & 9.012186 \text{ amu} \\
{}^{4}_{2}He & - & \underline{4.002603 \text{ amu}} \\
 & & 13.014789 \text{ amu}
\end{array}
$$

The total mass of the product is:

$$
\begin{array}{lcr}
{}^{1}_{0}n & - & 1.008665 \text{ amu} \\
{}^{12}_{6}C & - & \underline{12.000000 \text{ amu}} \\
 & & 13.008665 \text{ amu}
\end{array}
$$

The mass difference is:

$$
\begin{array}{r}
13.014789 \text{ amu} \\
\underline{13.008665 \text{ amu}} \\
0.006124 \text{ amu}
\end{array}
$$

From Einstein's equation (par. 1.6) it has been shown that the energy equivalent of one atomic mass unit is 931.48 Mev (million electron volts). Therefore, the energy (Q) associated with the above reaction is:

$$0.006124 \times 931.48 \frac{\text{Mev}}{\text{amu}} = \underline{5.704384 \text{ Mev}}$$

and we, therefore, see that in this reaction 5.7044 Mev of energy is released.

2.9. FISSION AND FUSION

a. General. So far, our discussion of induced radioactivity and energy release has been associated with reactions of laboratory and academic interest. For nuclear weapons, in addition to the necessity for a net decrease in mass in a nuclear process, the release of nuclear energy in amounts sufficient to cause an explosion requires that the reaction should be able to reproduce itself once it has started. Two artificially induced nuclear reactions that satisfy the conditions for the production of great amounts of energy in a very short interval of time are fission and fusion.

b. Fission.

(1) The fission process.

(a) The process of fission involves the splitting of very large nuclei, such as those of uranium-235 or plutonium-239, into much smaller nuclei. This splitting releases a vast amount of energy when judged by our ordinary standards of comparison, such as the burning of coal or gasoline. The fission does not take place spontaneously but must be initiated deliberately by directing a stream of neutrons into a mass of uranium or plutonium which is properly arranged and is of the proper size. If an atom of fissionable material captures a neutron, it may fission into two smaller pieces. The fission of just one nucleus releases only a tiny amount of energy--too little to be measured by any known means. However, as has already been stated, even a very tiny piece of material contains a vast number of atoms. When the small energy release from one fission is multiplied by a great number of atoms, the total energy release is enormous.

(b) There are several dozen different reactions that can occur in fissioning; that is, not every atom which fissions forms the same product nuclei. A few examples of fission reactions that are known to occur are as follows:

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{94}_{38}Sr + {}^{140}_{54}Xe + (2\text{-}3)\,{}^{1}_{0}n + Q $$

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{95}_{42}Mo + {}^{139}_{50}Sn + (2\text{-}3)\,{}^{1}_{0}n + Q $$

A generalized equation can be written to represent the fission process, making use of the symbol "FP" to stand for any fission product. This equation is:

$$ {}^{235}_{92}U + {}^{1}_{0}n \rightarrow FP_1 + FP_2 + (2\text{-}3)\,{}^{1}_{0}n + Q $$

In this generalized fission reaction equation, there are two or more neutrons released for every one that enters. The release of additional neutrons in the fission reaction is the reason that fission is a practical means of releasing energy, either in a weapon or in a nuclear reactor. The neutrons released in the fission reaction permit the development of the <u>chain reaction</u> that occurs in a fission weapon.

(2) <u>Chain reaction--criticality</u>.

(<u>a</u>) Because of the fact that at least two neutrons are released every time a uranium atom is split, it is possible to make a chain reaction occur. In other words, the two or more neutrons released may be made to fission two or more uranium nuclei, causing each of these nuclei to release two or more neutrons. These neutrons may fission more nuclei, producing more neutrons, and so on until a great many nuclei have been split. Since only a small amount of energy is released when one atom is fissioned, a great number of atoms must be fissioned in order to obtain a large amount of energy. This is best attained by creating a chain reaction. A fission chain reaction, such as that described above, is known as a multiplying chain reaction and it occurs extremely rapidly. A tremendous amount of energy is released in a very short time, and an explosion results.

(<u>b</u>) In order to create a chain reaction, certain conditions must be satisfied. If one of the atoms in a piece of fissionable material (^{235}U) is caused to fission by bombarding it with a neutron, the two or more neutrons released by the fissioning could do one of three things. They could--

<u>1</u>. Strike other uranium nuclei and cause them to fission.

<u>2</u>. Pass between the uranium atoms and completely escape from the piece of material without causing any further fission. (Remember that atoms are largely empty space.)

3. Strike nuclei (uranium or impurities) and not cause fission; in other words, be captured by the nuclei.

(c) Obviously, for a chain reaction to occur, at least one of the neutrons produced per fission must strike a uranium nucleus and cause another fission to occur. In order to make this happen, we must minimize the escape and nonfission capture.

1. Nonfission capture may be minimized by using very pure fissionable material because impurities tend to capture the neutrons and prevent fission.

2. Escape may be minimized by having sufficient fissionable material available or by using a neutron reflector. To visualize this, imagine a small, spherical piece of fissionable material in which a fission occurs. There are relatively few nuclei available within the fissionable material that the two neutrons produced by the fission may hit before they escape. Therefore, the probability of their striking other fissionable nuclei is very slight. If one of the neutrons happens to strike a nucleus and thereby causes it to fission, the probability of one of the second pair of neutrons striking a nucleus before escaping is very slight. Therefore, the reaction will quickly die down. A reaction of this type is called nonsustaining. A piece of fissionable material such as this is called a subcritical mass (fig. 2.9a). If more material is added around the sphere, the neutrons have more nuclei which they may hit before they escape and the probability of their striking nuclei is much greater. If enough fissionable material is present so that at least one neutron from every fission strikes another nucleus and causes it to fission, the reaction will continue in a steady manner and is called a sustaining chain reaction (figure 2.9b). A piece of fissionable material in which a steady reaction occurs is called a critical mass. Energy is released in a steady controllable manner, such as in a nuclear reactor used for producing power. If still more material is added to the sphere, more than one neutron per fission may strike a nucleus to cause further fission. When this occurs, the chain reaction will increase very rapidly and is called a multiplying chain reaction (figure 2.9c). In this case, we have what is known as a supercritical mass. The energy is released very quickly and cannot be controlled.

(3) Fission-type nuclear weapons.

(a) From the previous discussion, it is apparent that a supercritical mass is necessary to cause a nuclear

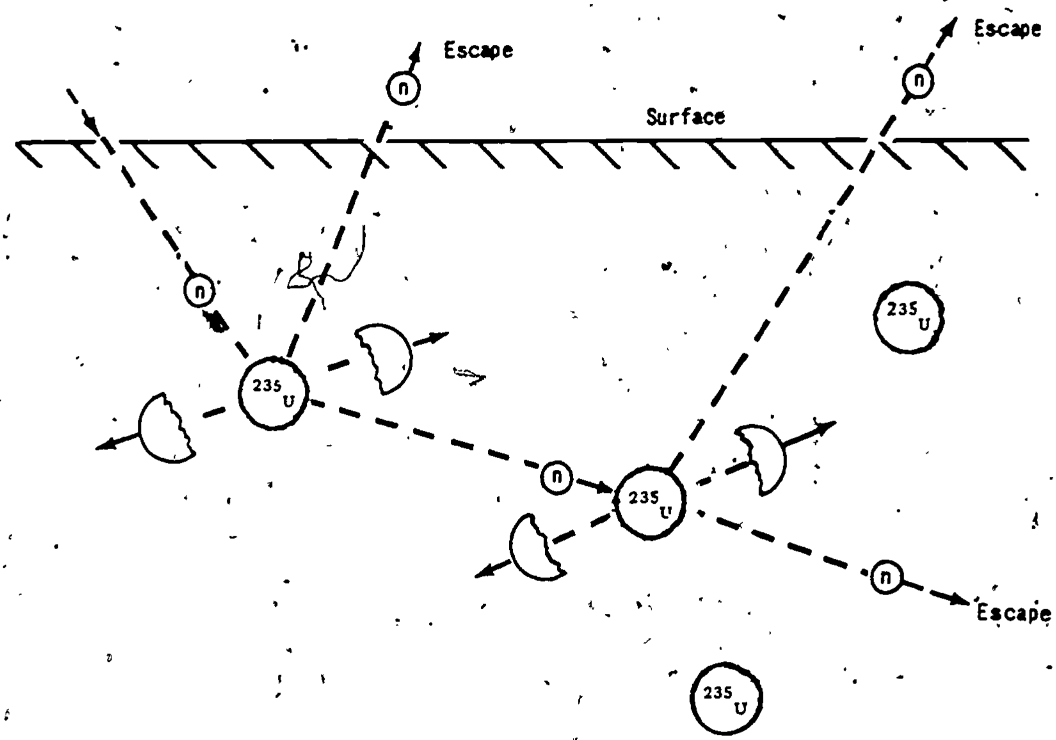


Figure 2.9a. Nonsustaining chain reaction in a subcritical mass.

detonation. However, it is unsafe to assemble a supercritical mass of fissionable material until the moment the explosion is desired because there are always stray neutrons that could start a chain reaction. To overcome this difficulty, the fissionable material may be kept in two separate subcritical masses within the weapon. When desired, these two pieces can be brought together to form a supercritical mass, which then detonates. Weapons employing this principle are know as "gun-type" weapons because one subcritical mass is actually shot through a gun tube into the other subcritical mass when the explosion is desired (figure 2.9d).

(b) There is another method of making a subcritical mass become supercritical. If, instead of adding more material to a subcritical mass, we compress the subcritical mass so that the atoms are closer together, we obtain much the same effect. If the atoms are closer together, the probability that a neutron will strike one and cause fission is greatly increased because there is less room to get between the atoms. This principle is also employed in

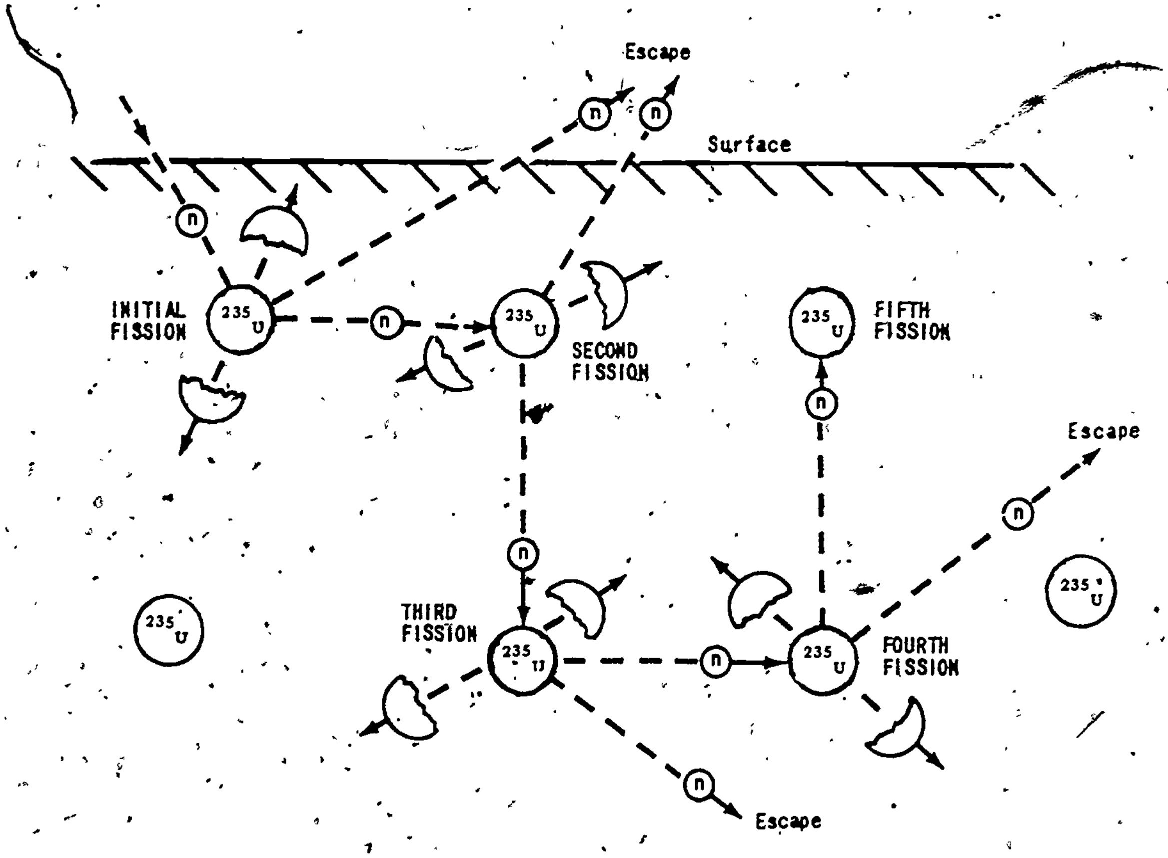


Figure 2.9b. Sustaining chain reaction in a critical mass.

nuclear weapons. A subcritical mass is surrounded by a charge of high explosive. When the explosive is detonated, the pressure created compresses the fissionable material, making it supercritical and, consequently, making it explode. Weapons employing this principle are known as "implosion" weapons (figure 2.9e) because the high explosive is arranged so that it implodes or exerts the major portion of its explosive force inward.

(4) Nuclear reactors. A peacetime application of nuclear fission is the ~~nuclear reactor~~. A sustaining chain reaction is made to occur in a critical mass of fissionable material. Water or some other fluid is circulated within the reactor where it is heated by the energy released. The steam produced can be used to run a turbine, which in turn can run an electrical generator to supply useful power. The Army now has a nuclear reactor--the Army package power reactor--the components of which are air-transportable. The reactor can be assembled at an advanced base and will produce electrical power for approximately 1.5 years without refueling.

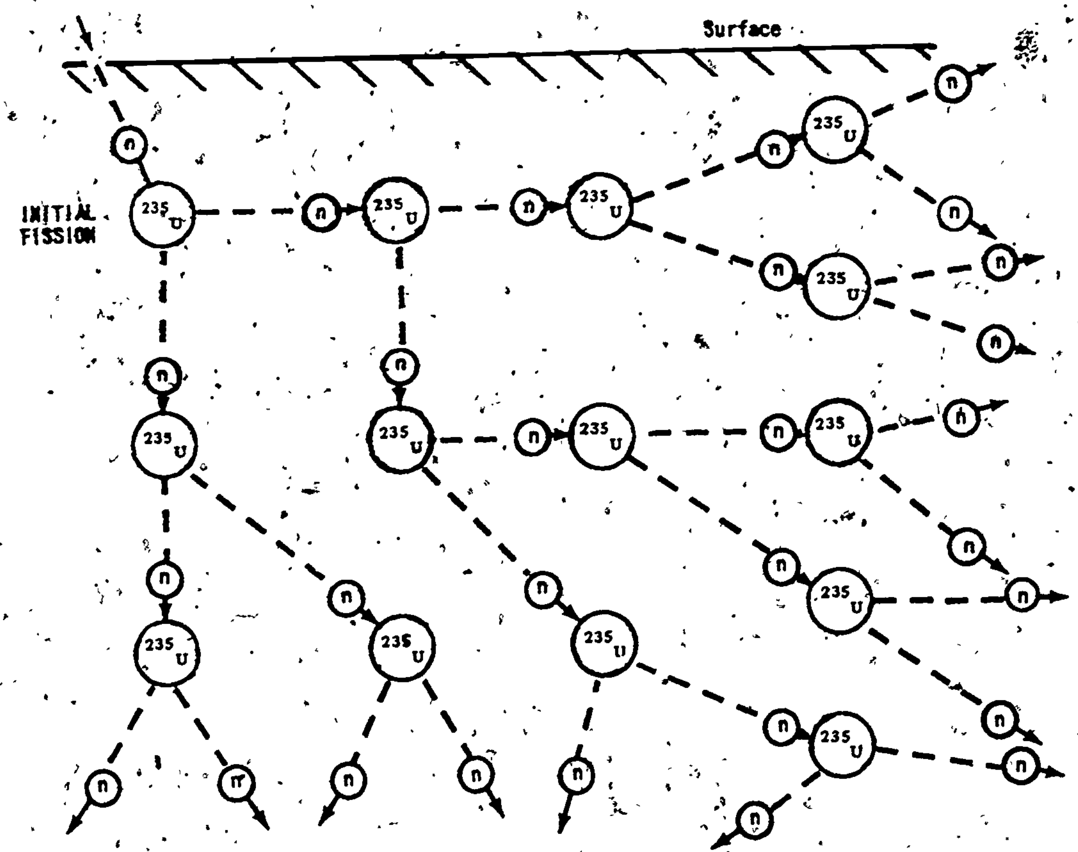


Figure 2.9c. Multiplying chain reaction in a supercritical mass.

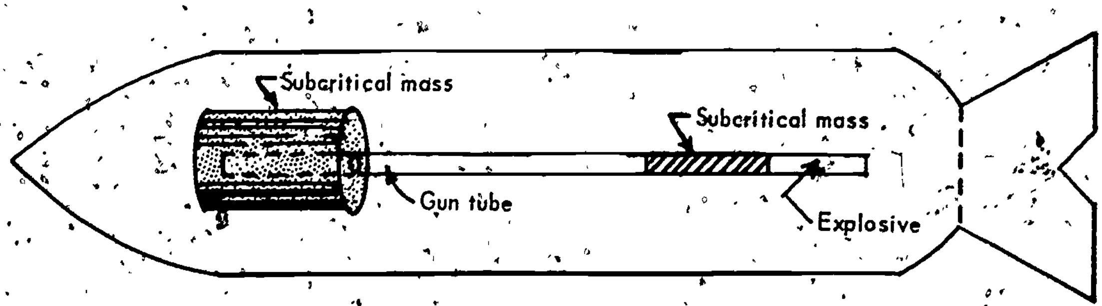


Figure 2.9d. Gun-type nuclear weapon.

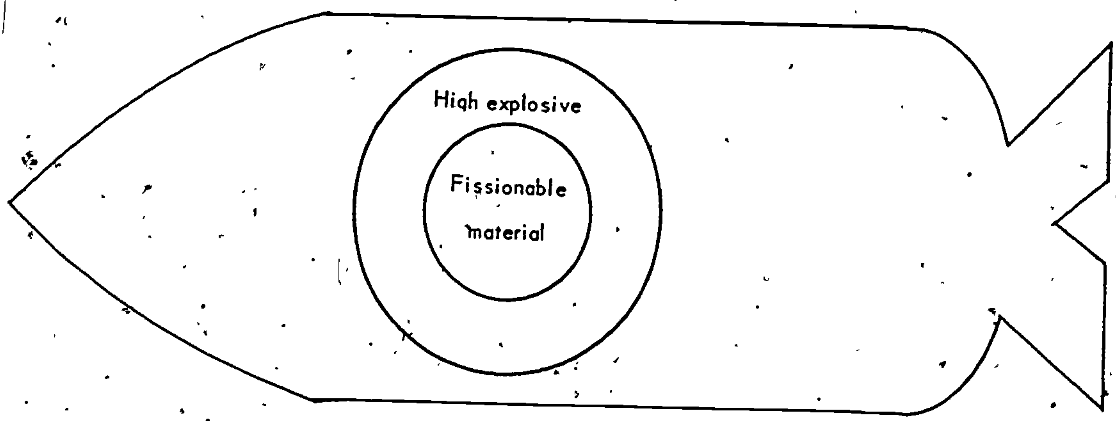


Figure 2.9e. Implosion-type nuclear weapon.

c. Fusion.

(1) Although it seems peculiar, a process that is the exact opposite of fission is also capable of releasing great quantities of energy. This process is only possible at the lower end of the scale of elements and involves uniting two small atoms into one larger atom. This process is called fusion. Specifically, an atom of one isotope of hydrogen unites with an atom of the same or a different isotope of hydrogen to form an isotope of helium. In addition to the generalized fusion reaction, normally written

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n + Q$$

there are several other possible reactions which may occur. They are:

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{1}_{1}H + Q$$

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n + Q$$

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{3}_{2}He + 2^{1}_{0}n + Q$$

Although neutrons may be produced in the reaction, they are not necessary to initiate it, as in the case of fission;

therefore, chain reactions are of no concern here. The conditions necessary to initiate the reactions are tremendous heat and pressure.

(2) It has been known for about 20 years that this reaction was theoretically possible and that, if it could be brought about, a weapon could be made with destructive power far beyond that of the ordinary atomic or fission bomb. It was also known that the only way to make the reaction occur was to subject a mass of hydrogen to temperatures in the order of hundreds of thousands of degrees and to pressures in the order of tens of thousands of pounds per square inch. The only way known to achieve such temperatures and pressures is by means of a fission explosion. Therefore, in fusion weapons the fusion reaction is set off by the heat and pressure from a fission detonation. In other words, the hydrogen bomb is a two-stage weapon; first fission occurs, then fusion.

(3) Each individual atom in a fission reaction releases more energy than an individual atom in a fusion reaction. However, a pound of hydrogen will release as much as four times more energy than a pound of uranium because of the large number of atoms contained in a pound of hydrogen.

(4) The fusion reaction has several other advantages. The fuel required is relatively cheap, and the supply is unlimited. Also, the products of the fusion reaction are not radioactive. The radioactivity that results from the detonation of a fusion weapon comes from the fission products of the fission component used to initiate the fusion reaction and also from neutron-induced activity. By reducing the size of the fission component as much as possible, the residual radioactivity can be reduced, thus producing a "cleaner" bomb.

(5) Research is now being conducted to make a fusion reaction occur without a fission initiator so that the reaction can be harnessed to produce power for peacetime purposes. A reactor of this type would have several advantages over the fission reactors now in existence. The fuel would be cheap and plentiful, and there would be no radioactive waste products.

RADIOACTIVITY

DB040, RADIOACTIVITY

I. Reference: ST 3-155, Chapter 2, paragraph 2.1-2.7, Chapter 3, paragraph 3.4-3.7.

II. Lesson Objectives and Notes:

A. Basic concepts of radioactivity.

B. Concept of decay and half-life.

C. Mathematical method of solution of single isotope decay problems.

PROPERTIES OF NUCLEAR RADIATION

Radiation	Symbol	Nature	Mass	Charge	Source
Alpha	α, ${}^{4}_{2}He$	Helium Nucleus	4 AMU	+2	Radioactive Material
Beta	β^{-}, ${}^{0}_{-1}e$	High-speed Electron	1/1845 AMU	-1	Radioactive Material
Gamma	${}^{0}_{0}\gamma$	Electromagnetic Energy	0	0	Radioactive Material
Neutron	${}^{1}_{0}n$	Nuclear Particle	1 AMU	0	Fission Reactions
Positron	β^{+}, ${}^{0}_{+1}e$	Positive Electron	1/1845 AMU	+1	Radioactive Material

RADIOACTIVE DECAY

Type of Decay	Symbol	Effect on A	Effect on Z	Example
Alpha	α, ${}^{4}_{2}He$	-4	-2	${}^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th + Q$
Beta	β^-, ${}^{0}_{-1}e$	0	+1	${}^{234}_{90}Th \rightarrow {}^{0}_{-1}e + {}^{234}_{91}Pa + Q$ ${}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$
Gamma	γ	0	0	${}^{129}_{53}I \rightarrow {}^{0}_{-1}e + {}^{129m}_{54}Xe + Q$ ${}^{129m}_{54}Xe \rightarrow {}^{0}_{0}\gamma + {}^{129}_{54}Xe + Q$
Positron	β^+, ${}^{0}_{+1}e$	0	-1	${}^{54}_{27}Co \rightarrow {}^{0}_{+1}e + {}^{54}_{26}Fe + Q$ ${}^{1}_{1}p \rightarrow {}^{0}_{+1}e + {}^{1}_{0}n$
Electron Capture	E.C.	0	-1	${}^{131}_{55}Cs + {}^{0}_{-1}e \rightarrow {}^{131}_{54}Xe$ ${}^{7}_{4}Be + {}^{0}_{-1}e \rightarrow {}^{7}_{3}Li + \gamma$ + (X-rays)

Examples of Induced Reactions

1. $^{27}_{13}Al + ^{1}_{0}n \rightarrow ^{28}_{13}Al + Q$

   $^{28}_{13}Al \rightarrow ^{0}_{-1}e + ^{0}_{0}\gamma + ^{28}_{14}Si + Q$

2. $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{1}_{0}n + ^{12}_{6}C + Q$

3. $^{23}_{11}Na + ^{1}_{0}n \rightarrow ^{4}_{2}He + ^{20}_{9}F + Q$

4. $^{14}_{7}N + ^{1}_{0}n \rightarrow ^{1}_{1}H + ^{14}_{6}C + Q$

5. $^{235}_{92}U + ^{1}_{0}n \rightarrow FP_1 + FP_2 + 2\text{-}3(^{1}_{0}n) + Q$

III. Handouts: None.

IV. Problems.

A. Class Example Problems - Radioactive Decay.

SYMBOLS:

R_o = Dose rate at the beginning of time period under consideration.

R = Dose rate at the end of time period under consideration.

t = The time of the dose rate reading R.

$t_{1/2}$ = The half-life (time) of the radionuclide under consideration.

n = Number of half-lives ($n = \frac{t}{t_{1/2}}$)

EQUATION: $2^n = \frac{R_o}{R}$

Safe siding features of 2^n table. If the values are exactly the same as those in the table, use them; if they are not exact, there is no interpolation. When solving for --

t - enter the 2^n table with the first value mathematically above the R_o/R value.

$t_{1/2}$ - enter the 2^n table with the first value mathematically below the R_o/R value.

R - enter the n table with the first value mathematically below the $t/t_{1/2}$ value.

R_o - enter the n table with the first value mathematically above the $t/t_{1/2}$ value.

1. A certain radioactive isotope which you are to use for calibrating your instruments has a half-life of 4 years. When you received a standard sample 5 years ago it gave a reading of 20 mrad/hr on your meter at a distance of 1 meter. What reading on your instrument should you find today at the same distance?

R_o = $t_{1/2}$ =

R = t =

2. Magnesium-27 decays by beta and gamma emission to form stable aluminum-27. The half-life of this process is 10 minutes. If a gamma dose rate of 40 rad/hr is obtained from a sample of pure ^{27}Mg, how long after the initial reading would it be before the dose rate has dropped to 6 rad/hr?

R_o =

R =

$t_{1/2}$ =

t =

3. An isotope whose half-life is unknown was delivered to the U.S. Army Ordnance Center and School. The dose rate reading taken upon the arrival of the isotope was 30 rad/hr. A second reading was taken 6 hours later and was found to be 18 rad/hr. What is the half-life of the isotope?

R_o =

R =

$t_{1/2}$ =

t =

B. Home Study Problems - Radioactive Decay and Half-life.

1. When you receive a sample of a single radioactive nuclide which is known to decay into a stable nuclide you find the dose rate is 60 mrad/hr at a distance of 1 meter from the sample. This nuclide is known to have a half-life of 3 days. When will the dose rate be reduced to 20 mrad/hr at the same distance?

2. A series of dose rate readings on the decay of a single nuclide sample which is known to decay into a stable nuclide are recorded as follows:

Time	Dose Rate (mrad/hr)
0 hour	610
6 hours	100

What is the half-life of this nuclide?

3. Given a single radioactive nuclide which gives a dose rate of 2,800 mrad/hr. The half-life of this nuclide is reported in the manuals as 3.8 days. When will the dose rate fall to 500 mrad/hr?

4. Given a single radioactive isotope which gives a dose rate of 540 mrad/hr. The half-life of this isotope is reported in the manuals as 4.8 days. What will be the reading after 36 days have elapsed?

5. A certain radioactive isotope has a half-life of 64 minutes. If the dose rate reading of the isotope 5 1/2 hours after its arrival was 120 mrad/hr, what was the dose rate of the isotope when it arrived?

6. A series of dose rate readings taken on the decay of a single nuclide are recorded as follows after you receive it:

Time	Dose Rate (mrad/hr)
2 Hours	150
3 Hours	130

a. What is the half-life of this nuclide?

b. What was the dose rate when you received this sample?

c. When will the dose rate be reduced to 25 mrad/hr?

7. For use in calibrating your radiac instruments you have been given a sample of cobalt($^{60}_{27}Co$). This nuclide decays by a process of beta and gamma emissions into stable nickel ($^{60}_{28}Ni$). The half-life of this material is known to be 5.3 years. When your sample was prepared 3 years ago, it was found to give a dose rate of 320 mrad/hr at a distance of 130 cm.

a. What should be the dose rate at the same distance today?

b. When can you expect the dose rate to be 100 mrad/hr at a distance of 130 cm?

8. Cesium ($^{137}_{55}Cs$) is radioactive and gives up a beta particle and gamma radiation to become a stable nuclide of barium ($^{137}_{56}Ba$). The half-life of this cesium nuclide is 30 years. Assume when you received a sample of this cesium nuclide 13 years ago it gave a dose rate of 120 rad/hr. What should the dose rate be today?

9. After an underwater burst in salt water some of the stable sodium ($^{23}_{11}$Na) is converted into a radioactive nuclide of sodium ($^{24}_{11}$Na). This radioactive sodium decays by beta and gamma emissions into stable magnesium ($^{24}_{12}$Mg). An initial reading taken on a sample of the radioactive sodium gave a dose rate of 240 rad/hr. A second reading taken 6 hours later gave a dose rate of 180 rad/hr.

a. What is the half-life of the sodium sample?

b. When will the dose rate be 150 rad/hr?

(NOTE: All dose rate readings calculated at a distance of one meter from the sample.)

V. Solution to Problems.

A. Solution to Class Problems.

Problem 1

a. Given: $R_o = 20$ mrad/hr

$t_{1/2} = 4$ years

$t = 5$ years

$R = ?$

b. Using the two equations

$$2^n = \frac{R_o}{R}; \quad n = \frac{t}{t_{1/2}}$$

Since both t and $t_{1/2}$ are known, solve

$$n = \frac{t}{t_{1/2}} \text{ first.}$$

$$n = \frac{t}{t_{1/2}} = \frac{5}{4} = 1.25$$

c. Enter the 2^n table found in Appendix II. In the n column look for a value of 1.2. The corresponding value for 2^n is 2.300.

d. Solve the $2^n = \frac{R_o}{R}$ equation.

$$2.300 = \frac{20}{R}$$

$$R = \frac{20}{2.3}$$

$$R = \underline{\underline{8.7 \text{ mrad/hr}}}$$

Problem 2.

a. Given: $R_o = 40$ rad/hr

$R = 6$ rad/hr

$t_{1/2} = 10$ minutes

$t = ?$

b. Solve $2^n = \frac{R_o}{R}$ first.

$$2^n = \frac{40}{6} = 6.67$$

c. Enter 2^n table, safe side by selecting the larger value find $n = 2.8$.

d. Solve $n = \frac{t}{t_{1/2}}$

$$2.8 = \frac{t}{10 \text{ minutes}}$$

$$t = \underline{\underline{28 \text{ minutes}}}$$

Problem 3.

a. Given: $R_o = 30$ rad/hr

$R = 18$ rad/hr

$t = 6$ hours

$t_{1/2} = ?$

b. Solve $2^n = \frac{R_o}{R}$

$$2^n = \frac{30}{18} = 1.67$$

c. Enter 2^n table, safe side by selecting

$$n = 0.7$$

d. Solve $n = \frac{t}{t_{1/2}}$

$$0.7 = \frac{6}{t_{1/2}}$$

$$t_{1/2} = \frac{6}{0.7} = \underline{\underline{8.57 \text{ hours}}}$$

B. Solution to Home Study Problems.

Problem 1.

a. Given: $R_o = 60$ mrad/hr

$R = 20$ mrad/hr

$t_{1/2} = 3$ days

$t = ?$

b. Using the two equations

$$2^n = \frac{R_o}{R}; \quad n = \frac{t}{t_{1/2}}$$

since both R and R_o are known, solve

$$2^n = \frac{R_o}{R} \text{ first.}$$

$$2^n = \frac{R_o}{R} = \frac{60}{20} = 3.$$

c. Enter the 2^n Table found in Appendix II. In the 2^n column look for a value of 3. This values lies between $2^n = 2.830$ and $2^n = 3.030$. In order to determine which value to use look at the guide for safe siding at the top of the chart. Since the unknown is "t," the larger value of 2^n should be selected. The value for n corresponding to $2^n = 3.03$ is $n = 1.6$.

d. Solve the $n = \frac{t}{t_{1/2}}$ equation.

$$1.6 = \frac{t}{3}$$

$$t = 3(1.6)$$

$$t = \underline{\underline{4.8 \text{ days}}}$$

<u>Problem 2.</u>

a. Given: $R_o = 610$ mrad/hr

$R = 100$ mrad/hr

$t = 6$ hours

$t_{1/2} = ?$

b. Solve $2^n = \frac{R_o}{R}$ first.

$$2^n = \frac{610}{100} = 6.1$$

c. Enter 2^n table, safe side by selecting the smaller value

find $n = 2.6$

d. Solve $n = \frac{t}{t_{1/2}}$

$$2.6 = \frac{6}{t_{1/2}}$$

$$t_{1/2} = \frac{6}{2.6} = \underline{\underline{2.31 \text{ hours}}}$$

Problem 3.

a. Given: $R_o = 2800$ mrad/hr

$R = 500$ mrad/hr

$t_{1/2} = 3.8$ days

$t = ?$

b. Solve $2^n = \frac{R_o}{R} = \frac{2800}{500}$

$2^n = 5.6$

c. Enter 2^n table, safe side by selecting $n = 2.5$.

d. Solve $n = \frac{t}{t_{1/2}}$

$2.5 = \frac{t}{3.8}$

$t = 2.5\ (3.8) = \underline{\underline{9.5 \text{ days}}}$

Problem 4.

a. Given: $R_o = 540$ mrad/hr

$R = ?$

$t = 36$ days

$t_{1/2} = 4.8$ days

b. Solve $n = \frac{t}{t_{1/2}}$ for n.

$n = \frac{36}{4.8} = 7.5$

c. Enter 2^n table and find $2^n = 181$.

d. Solve $2^n = \frac{R_o}{R}$

$$\therefore R = \frac{R_o}{2^n} = \frac{540}{181}$$

$$R = \underline{\underline{2.98 \text{ mrad/hr}}}$$

Problem 5.

a. Given: $R_o = ?$

$R = 120$ mrad/hr

$t = 5\ 1/2$ hours (330 minutes)

$t_{1/2} = 64$ minutes

b. Solve $n = \frac{t}{t_{1/2}}$

$$n = \frac{330}{64} = 5.16$$

c. Enter 2^n table. Find $2^n = 36.7$.

d. Solve $2^n = \frac{R_o}{R}$

$$R_o = 2^n R = 36.7(120)$$

$$R_o = 4400 \text{ mrad/hr}$$

or $\underline{\underline{4.4 \text{ rad/hr}}}$

Problem 6a.

a. Given: $R_o = 150$ mrad/hr

$R = 130$ mrad/hr

$t = 1$ hour

$t_{1/2} = ?$

b. Solve $2^n = \frac{R_o}{R} = \frac{150}{130}$

$$2^n = 1.15$$

c. Enter 2^n table. Find $n = 0.2$.

d. Solve $n = \frac{t}{t_{1/2}}$

$$t_{1/2} = \frac{t}{n} = \frac{1}{0.2}$$

$$t_{1/2} = \underline{\underline{5 \text{ hours}}}$$

Problem 6b.

a. Given: $R_o = ?$

$R = 150$ mrad/hr

$t = 2$ hours

$t_{1/2} = 5$ hours (from part a)

b. Solve $n = \frac{t}{t_{1/2}} = \frac{2}{5}$

$$n = 0.4$$

c. Enter 2^n table. Find $2^n = 1.32$.

d. Solve $R = \frac{R_o}{2^n}$

$$R_o = 2^n(R)$$

$$R_o = 1.32\ (150) = \underline{\underline{198 \text{ mrad/hr}}}$$

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Problem 6c.

a. Given: $R_o = 198$ mrad/hr

$R = 25$ mrad/hr

$t = ?$

$t_{1/2} = 5$ hours

b. Solve $2^n = \frac{R_o}{R} = \frac{198}{25}$

$2^n = 7.92$

c. Enter 2^n table. Find $n = 3$.

d. Solve $n = \frac{t}{t_{1/2}}$

$t = nt_{1/2} = 3(5)$

$t = \underline{\underline{15 \text{ hours}}}$

Problem 7a.

a. Given: $R_o = 320$ mrad/hr

$R = ?$

$t = 3$ years

$t_{1/2} = 5.3$ years

b. Solve $n = \frac{t}{t_{1/2}} = \frac{3}{5.3}$

$n = 0.566$

c. Enter 2^n table. Find $2^n = 1.415$.

d. Solve $R = \frac{R_o}{2^n}$

$$R = \frac{320}{1.415} = \underline{\underline{226 \text{ mrad/hr}}}$$

Problem 7b.

a. Given: $R_o = 320$ mrad/hr

$R = 100$ mrad/hr

$t = ?$

$t_{1/2} = 5.3$ years

b. Solve $2^n = \frac{R_o}{R} = \frac{320}{100}$

$$2^n = 3.2$$

c. Enter 2^n table. Find $n = 1.7$.

d. Solve $n = \frac{t}{t_{1/2}}$

$$n = nt_{1/2} = 1.7(5.3)$$

$$t = \underline{\underline{9.01 \text{ years}}}$$

Problem 8.

a. Given: $R_o = 120$ rad/hr

$R = ?$

$t = 13$ years

$t_{1/2} = 30$ years

b. Solve $n = \frac{t}{t_{1/2}}$

$$n = \frac{13}{30} = 0.434$$

c. Enter 2^n table. Find $2^n = 1.32$.

d. Solve $R = \frac{R_o}{2^n}$

$$R = \frac{120}{1.32} = \underline{\underline{90.9 \text{ rad/hr}}}$$

Problem 9a.

a. Given: $R_o = 240$ rad/hr

$R = 180$ rad/hr

$t = 6$ hours

$t_{1/2} = ?$

b. Solve $2^n = \frac{R_o}{R}$

$$2^n = \frac{240}{180} = 1.33$$

c. Enter 2^n table. Find $n = 0.4$.

d. Solve $n = \frac{t}{t_{1/2}}$

$$t_{1/2} = \frac{t}{n} = \frac{6 \text{ hours}}{0.4}$$

$$t_{1/2} = \underline{\underline{15 \text{ hours}}}$$

Problem 9b.

a. Given: $R_o = 240$ rad/hr

$R = 150$ rad/hr

$t = ?$

$t_{1/2} = 15$ hours

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b. Solve $2^n = \frac{R_o}{R} = \frac{240}{150}$

$2^n = 1.6$

c. Enter 2^n table. Find $n = 0.7$.

d. Solve $n = \frac{t}{t_{1/2}}$

$0.7 = \frac{t}{15}$

$t = 0.7\,(15) = \underline{\underline{10.5 \text{ hours}}}$

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RADIATION UNITS

DF020

DF020, RADIATION UNITS

I. Discussion and References.

NOTE: The definitions and concepts given below are taken from the recommendations adopted by the National Bureau of Standards as of 1959. Reference: "Report of the International Commission on Radiological Units and Measurements (ICRU), 1959," Handbook 78, U. S. Department of Commerce, National Bureau of Standards.

A. Exposure Dose.

1. Exposure dose of X or Gamma radiation at a certain place is a measure of the radiation that is based upon its ability to produce ionization.

2. The unit of exposure dose of X or gamma radiation is the ROENTGEN (r). One roentgen is an exposure of X or gamma radiation such that associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying 1 electrostatic unit of electricity of either sign.

$$1r = \frac{1 \text{ esu}}{\text{cm}^3} \text{ of air at standard temperature and pressure.}$$

3. A subsidiary unit is: 1 milliroentgen (mr) $= \frac{1}{1000}$ r.

4. The roentgen is also equivalent to the following:

   a. 87 (approx) ergs of energy absorbed per gram of air.

   b. 98 (approx average) ergs of energy absorbed per gram of soft tissue.

B. Absorbed Dose.

1. Absorbed dose of any ionizing radiation is the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest.

2. The unit of absorbed dose is the RAD. One rad is the absorption of 100 ergs of energy per gram of absorber. (100 ergs/gm)

3. The rad is a measure of absorbed dose from any kind of radiation in any medium in terms of fundamental energy units.

   a. The rad puts all energy absorption on the same level.

   b. The energy absorbed by matter due to X or gamma shows up primarily as the electrons ejected from atoms by incident radiation upon a piece of matter, and these electrons cause essentially all of the ionizations noted in energy absorption.

c. Roentgen considers only X and gamma while the rad considers all types of radiation.

4. It should be observed that the values of so-called "roentgen equivalency" given in para A4a and b above are actually statements of the absorbed dose in two media resulting from an exposure dose of one roentgen.

Medium	Exposure Dose (ionization in air)	Absorbed Dose (energy absorbed in medium)	Ratio $\frac{rad}{r}$
Air	1r	0.87 rad	0.87
Soft Tissue	1r	0.98 rad	0.98

The ratio of rad absorbed per roentgen of exposure has been given the symbol f (no special name). That is, $f = \frac{rad}{r}$. From a knowledge of "f" and exposure dose in roentgen, the absorbed dose can be calculated. Some values of "f" for particular tissues are presented in Handbook 78. However, at the present time, this information is not directly applicable to military problems because it deals only with specific tissues.

5. The distinction between "exposure dose" and "absorbed dose" should be made clear.

   a. Exposure dose is that radiation which is available to be absorbed.

   b. Absorbed dose is that radiation which is actually absorbed in the body.

6. Another unit of absorbed dose is the REP (roentgen equivalent physical). It may be defined in either of two ways:

   a. One rep is that quantity of any ionizing radiation which results in the absorption of the same amount of energy in soft tissue as that resulting from exposure to one roentgen of X or gamma radiation.

   b. One rep is that quantity of any ionizing radiation which results in the absorption of 93 ergs/gram of soft tissue.

7. The rep was the first unit of absorbed dose defined. Because it is not precise and is limited to one kind of absorbing material, it is being supplanted by the rad. However, it remains in a good many specifications of permissible doses. Also, other values than 93 ergs/gram may be found in older definitions of the rep.

8. Another unit of absorbed dose is the REM (roentgen equivalent man). One rem is an absorbed dose of any ionizing radiation which will produce the same biological effect in man as the absorbed dose from exposure to one roentgen of X or gamma radiation.

9. The rem is a rather loosely defined term but it has the important merit that it places all kinds of radiation on an equal level. That is, 1 rem of gamma + 1 rem of alpha equals 2 rem of absorbed radiation.

10. A rad of one kind of radiation does not necessarily produce the same biological effect as a rad of another kind. The difference in biological effectiveness is given in terms of the RBE (relative biological effectiveness).

> "The statement that 'the RBE of α radiation relative to γ radiation is 10' signifies that m rad of α radiation produces a particular biological response in the same degree as 10 m rad of γ radiation."

In other words,

$$\text{rem} = \text{rad} \times \text{RBE}.$$

11. Some commonly accepted values of RBE are given below.

Type of Radiation	RBE
X or γ rays	1
Beta particles	1
Fast neutrons	10
Slow (thermal) neutrons	5
Alpha particles	10-20

12. Example of adding doses in rem.

Type of Radiation	Absorbed Dose rad		RBE		Absorbed Dose rem
Gamma	0.4	x	1	=	0.4
Thermal neutrons	0.5	x	5	=	2.5
Fast neutrons	0.2	x	10	=	2.0
			Total absorbed dose	=	4.9

C. Dose Rate.

1. Exposure dose rate is the exposure dose per unit time.

2. The unit of exposure dose rate is the roentgen per unit time.

3. The most commonly used units of exposure dose rate are:

   roentgens per hour (r/hr)

   milliroentgens per hour (mr/hr)

4. Absorbed dose rate is the absorbed dose per unit time.

5. The unit of absorbed dose rate is the rad per unit time.

6. The most commonly used units of absorbed dose rate are:

   rad per hour (rad/hr)

   millirad per hour (mrad/hr)

7. Dose and dose rate are related (if R is constant over the time T) by the equation:

$$D = RT,$$

where D = dose
R = dose rate
T = time

D. Activity.

1. All activity units are means of expressing the radiation output of a radioactive source.

2. The unit of quantity of radioactive material, evaluated according to its radioactivity, is the Curie (Ci). One curie is a quantity of radioactive isotope in which the number of disintegrations per second is 3.700×10^{10}.

3. Related units are:

1 microcurie = 1 µCi = $\frac{1}{1,000,000}$ curie = 10^{-6} curie.

1 millicurie = 1mCi = $\frac{1}{1,000}$ = 10^{-3} curie

1 megacurie = 1MCi = 1,000,000 curies = 10^{+6} curies.

4. Another unit of activity is the **rutherford** (Rd). One rutherford is a quantity of radioactive isotope in which the number of disintegrations per second is 10^6.

5. A unit of source strength which is convenient for many purposes is the RAD PER HOUR AT ONE METER (rhm). One rhm is the strength of a radioactive source which produces an exposure dose rate of 1 rad per hour at a distance of one meter.

6. A subsidiary unit is:

$$1 \text{ millirhm (mrhm)} = 1 \text{ mrad/hr at 1 meter}$$

$$= \frac{1}{1,000} \text{ rhm}$$

7. Knowing the source strength in rhm, it is possible to calculate the exposure dose rate at any distance from the source by means of the following equation:

$$R = \frac{S}{d^2}$$

where R = dose rate at distance d in rad/hr (or mrad/hr)

S = source strength in rhm (or mrhm)

d = distance from source in meters.

E. Summary.

1. One roentgen is equal to one electrostatic unit of charge per cubic centimeter of air at standard conditions.

2. One rad is equal to 100 ergs of energy absorbed per gram of absorber.

3. One rem is equal to the biological damage done by the absorption of one roentgen of X or gamma radiation.

4. RBE is a comparison between the effect of any type of radiation and the damage done by one roentgen of X or gamma radiation.

5. One curie is equal to 3.7×10^{10} disintegrations per second.

6. Rhm is a rad per hour at a distance of 1 meter.

F. Additional References of Interest: National Bureau of Standards Handbook 78, 84, 86, 87, 88.

II. Lesson Objectives and Notes:

A. Definition of dose units and their interrelationship.

B. Activity units and their physical meaning.

C. Units of source strength and methods of determining dose rate at various distances from the source.

III. Handout.

RADIATION UNITS

Activity Output of a Radioactive Source	Dose Amount of Radiation Received	
	EXPOSURE	ABSORBED
CURIE - Unit of quantity of radioactive material evaluated according to its radioactivity. 1 Curie = 3.7×10^{10} disintegrations per second 1 Microcurie = 1 μCi 1μCi = 10^{-6} Ci 1 Millicurie = 1 mCi 1 mCi = 10^{-3} Ci	MEASUREMENT OF IONIZATION IN AIR - UNIT ROENTGEN (r). 1r = 1 electrostatic unit of charge per 1cc of dry air at STP 1r = $\frac{\text{1 esu}}{\text{cc air at STP}}$	ENERGY ABSORBED PER UNIT MASS - Unit Rad (no abbreviation). 1 rad = the absorption of 100 ergs of energy per gram of absorbing material. 1 rad = $\frac{\text{100 ergs}}{\text{gram of absorber}}$ Biological Damage - Unit rem (roentgen equivalent man or mammal). 1 rem = damage done by exposure to 1 r of X or γ radiation.

UNIT OF SOURCE STRENGTH
(Neither Dose or Activity)

rhm = 1 rad per hour at a distance of one meter from the source.

$$R = \frac{S}{d^2}$$

R = dose rate in rad/hr or mrad/hr

S = source strength in rhm or mrhm

d = distance in meters.

IV. Problems - Radiation Units.

1. The ionization chamber in an instrument has a volume of 30 cm^3 filled with air at standard temperature and pressure. In a laboratory measurement the number of ionizations which occurred in this volume during a certain period was found to be equivalent to 4 esu of charge. What was the exposure dose at the position of the ion chamber?

2. In a laboratory experiment it was found that a sample of human tissue absorbed 480 ergs of energy from a beam of X-rays. The mass of the tissue was 8 grams. What was the absorbed dose in rad?

3. In the example in problem 2 the absorbed dose in tissue was due to 50% gamma radiation and 50% fast neutrons. What is the absorbed dose in rem in this tissue?

4. In a controlled experiment, one group of animals is exposed to 50 rad of fast neutrons, another group of animals is exposed to 150 rad of slow neutrons and a third group of animals is exposed to 400 roentgens of gamma radiation. If the end result is the same in each group of animals, what is --

a. the RBE for the fast neutrons?

b. the RBE for the slow neutrons?

5. In the example in problem 4, if one animal received all the radiation, fast neutrons, slow neutrons and gamma, what would be his total dose in rem? (Use RBEs found in problem 4)

6. In an experiment on laboratory animals, it was found that cataracts were produced by absorption of 30 rad of fast neutron radiation. However, 300 rad were necessary to produce the same effect with gamma radiation. Assuming one rad of gamma is equal to one roentgen of gamma, what is the RBE of fast neutrons for producing cataracts?

7. A worker in a nuclear reactor installation is subject to the following doses in rad: 0.001 rad of gamma radiation, 0.0002 rad of thermal neutrons, 0.0001 rad of fast neutrons.

   a. What total dose (in mrem) did the worker absorb?

   b. If this dose was received in 2 hours, what was the average dose rate?

   c. Will this worker exceed the permissible weekly whole body dose of 300 mrem if he works a 40-hour week? What dose will he receive in a week?

8. A sample of radioactive material is known to undergo 4.6×10^9 disintegrations per second. How many curies is it?

9. The number of disintegrations per second in a sample of Gallium-73 is known to be 6.6×10^4 at a certain time. How many curies of ^{73}Ga are in the sample? What is this quantity in microcuries?

10. A 2mCi ^{137}Cs point source gives an exposure dose rate of 6 rad/hr at a distance of 1 cm. What is the source strength of the source stated in rhm? in mrhm?

11. If a 250 mrhm source gave a dose rate reading of 5 mrad/hr, at what distance from the source was the reading taken?

12. A ^{137}Cs point source has a source strength of 100 mrhm.

a. What is the exposure dose rate at a distance of 3 meters from it?

b. At what distance would the dose rate be 20 mrad/hr?

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V. Solutions - Radiation Units.

1. $1\ esu/cm^3 = 1\ r$

$4\ esu/30\ cm^3 = \underline{\underline{0.133\ r}}$

2. $100\ ergs/1\ gm = 1\ rad$

$$\frac{480\ ergs}{8\ gm} \times \frac{1\ rad}{100\ ergs/gm} = \underline{\underline{0.6\ rad}}$$

3. rem = rad x RBE

rem for gamma = 0.3 rad x 1 = 0.3 rem

rem for fast neutrons = 0.3 rad x 10 = 3 rem

Total rem = $\underline{\underline{3.3}}$

4. 400 r of gamma = 400 rem

$$RBE = \frac{rem}{rad}$$

a. RBE for fast neutrons $= \frac{400\ rem}{50\ rad} = \underline{\underline{8}}$

b. RBE for slow neutrons $= \frac{400\ rem}{150\ rad} = \underline{\underline{2.667}}$

5. Total dose = 400 rem + 400 rem + 400 rem = $\underline{\underline{1200\ rem}}$

6. $RBE = \frac{rem}{rad}$

$RBE = \frac{300\ rem}{30\ rad}$

$RBE = \underline{\underline{10}}$

7. a. 1 mrad gamma x RBE (1) = 1 mrem

0.2 mrad thermal neutrons x RBE (5) = 1 mrem

0.1 mrad fast neutrons x RBE (10) = 1 mrem

Total Dose = $\underline{\underline{3\ mrem}}$

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7. b. $D = R \times T$

$R = \frac{D}{T}$

$R = \frac{3 \text{ mrem}}{2 \text{ hours}}$

$R = \underline{\underline{1.5 \text{ mrem/hr}}}$

c. No.

$D = R \times T$

$D = 1.5 \text{ mrem/hr} \times 40 \text{ hrs}$

$D = \underline{\underline{60 \text{ mrem}}}$

8. $1 \text{ curie} = 3.7 \times 10^{10} \text{ dis/sec}$

$$\frac{4.6 \times 10^{9} \text{ dis/sec}}{3.7 \times 10^{10} \text{ dis/sec/curie}} = \underline{\underline{0.124 \text{ curies}}}$$

9. $1 \text{ curie} = 3.7 \times 10^{10} \text{ dis/sec}$

$$\frac{6.6 \times 10^{4} \text{ dis/sec}}{3.7 \times 10^{10} \text{ dis/sec/curie}} = \underline{\underline{1.78 \times 10^{-6} \text{ Ci or } 1.78\ \mu\text{Ci}}}$$

10. $R = \frac{S}{d^2}$

$S = Rd^2$

$S = 6 \text{ rad/hr} \times (0.01 \text{ m})^2$

$S = 6 \text{ rad/hr} \times 0.0001 \text{ m}^2$

$S = 0.0006 \text{ rhm}$

$S = 0.0006 \times 1000 \frac{\text{mrhm}}{\text{rhm}}$

$S = \underline{\underline{0.6 \text{ mrhm}}}$

11. $R = \frac{S}{d^2}$

$d^2 = \frac{S}{R}$

$d^2 = \frac{250 \text{ mrhm}}{5 \text{ mrad/hr}}$

$d^2 = 50 \text{ m}^2$

$d = \underline{7.07 \text{ m}}$

12. a. $R = \frac{S}{d^2}$

$R = \frac{100 \text{ mrhm}}{(3\text{m})^2}$

$R = \frac{100 \text{ mrhm}}{9\text{m}^2}$

$R = \underline{11.11 \text{ mrad/hr}}$

b. $R = \frac{S}{d^2}$

$d^2 = \frac{S}{R}$

$d^2 = \frac{100 \text{ mrhm}}{20 \text{ mrad/hr}}$

$d^2 = 5 \text{ m}^2$

$d = \underline{2.24 \text{ meters}}$

VI. Additional Information - Extraction from Radiation Quantities and Units, International Commission on Radiological Units and Measurements (ICRU), Report 10a; Handbook 84, United States Department of Commerce, National Bureau of Standards.

RADIATION UNITS

In this report the ICRU recommends with considerable reluctance and some misgivings, the use of the symbol R instead of r for roentgen. Several recognized international groups working in the field of symbols and nomenclature including the International Council of Scientific Unions have agreed upon the convention that the first letter of abbreviations of units named after individuals should be capitalized. At least one country has already officially adopted the symbol R for roentgen. There are many indications that, however unnecessary, this trend will continue and hence the Commission has acceded to the pressure for change. As far as medical radiology is concerned, this change will result more in annoyance than confusion.

The ICRU recommends that the use of each special unit be restricted to one quantity as follows:

The rad - solely for absorbed dose
The roentgen - solely for exposure
The curie - solely for activity.

It recommends further that those who prefer to express quantities such as absorbed dose and kerma (see below) in the same units should use units of an internationally agreed coherent system.

Several new names are proposed in the present report. When the absorbed dose concept was adopted in 1953, the Commission recognized the need for a term to distinguish it from the quantity of which the roentgen is the unit. In 1956 the Commission proposed the term "exposure" for this latter quantity. To meet objections by the ICRP, a compromise term, "exposure dose" was agreed upon. While this term has come into some use since then, it has never been considered as completely satisfactory. In the meantime, the basic cause of the ICRP objection has largely disappeared since most legal codes use either the units rad or rem.

Since in this report the whole system of radiological quantities and units has come under critical review, it seemed appropriate to reconsider the 1956 decision. Numerous names were examined as a replacement for exposure dose, but there were serious objections to any which included the word "dose." There appeared to be a minimum of objection to the name exposure and hence this term has been adopted by the Commission with the hope that the question has been permanently settled. It involves a minimum change

from the older name exposure dose. Furthermore, the elimination of the term "dose" accomplishes the long-felt desire of the Commission to retain dose for one quantity only - the absorbed dose.

The term "RBE dose" has in past publications of the Commission not been included in the list of definitions but was merely presented as a "recognized symbol." In its 1959 report, the Commission also expressed misgivings over the utilization of the same term, "RBE," in both radiobiology and radiation protection. It now recommends that the term "RBE" be used in radiobiology only and that another name be used for the linear-energy-transfer-dependent factor by which absorbed doses are to be multiplied to obtain for purposes of radiation protection a quantity that expresses on a common scale for all ionizing radiations the irradiation incurred by exposed persons. The name recommended for this factor is the quality factor (QF). Provisions for other factors are also made. Thus a distribution factor (DF) may be used to express the modification of biological effect due to non-uniform distribution of internally deposited isotopes. The product of absorbed dose and modifying factors is termed the "dose equivalent (DE)." As a result of discussions between ICRU and ICRP the following formulation has been agreed upon:

The Dose Equivalent

1. For protection purposes it is useful to define a quantity which will be termed the "dose equivalent (DE)."

2. (DE) is defined as the product of absorbed dose, D, quality factor, (QF), dose distribution factor, (DF), and other necessary modifying factors.

   (DE) = D(QF)(DF) .....

3. The unit of dose equivalent is the "rem." The dose equivalent is numerically equal to the dose in rad multiplied by the appropriate modifying factors.

The quantity for which the curie is the unit was referred to the committee for a name and definition. Hitherto the curie has been defined as a quantity of the radioactive nuclide such that 3.7×10^{10} disintegrations per second occur in it. However, it has been specified what was meant by quantity of a nuclide, whether it be a number, mass, volume, etc. Meanwhile the custom has grown of identifying the number of curies of a radionuclide with its transformation rate. Because of the vagueness of the original concept, because of the custom of identifying curies with transformation rate and because it appeared not to interfere with any other use of the curie, the Commission recommends that the term "activity" be used for the transformation rate, and that the curie be made its unit.

It is recognized that the definition of the curie is of interest to other bodies in addition to the ICRU, but by this report we recommend that steps be taken to redefine it as $3.7 \times 10^{10}\ s^{-1}$, i.e., as a unit of activity and not of quantity of a nuclide.

It is also recommended that the term "specific gamma ray constant" be used instead of specific gamma ray emission for the quotient of the exposure rate at a given distance by the activity. The former ~~term~~ focuses attention on the constancy of this quotient for a given nuclide rather than the emission of the source.

INTRODUCTION TO PAM 25

DF030

DF030, INTRODUCTION TO PAM 25

I. Reference: Skim Pam 25. pages 1 - 217.

II. Lesson Outline.

A. Introduction.

B. Explanation.

In the introduction to this pamphlet, we briefly cover important topics through a page-by-page analysis, concentrating on the material the student will need most. The instruction is directly keyed to Pam 25.

1. Areas most used in Pam 25 are as follows:

   a. Atomic mass table, pages 51-64.

   b. Density of elements and common material, pages 65-66.

   c. List of elements, page 68.

   d. Universal decay table, pages 106-107.

   e. Beta attenuation curves, pages 122-123.

   f. Mass attenuation coefficients, pages 137-140.

   g. Glossary of terms, pages 413-441.

2. This book may be tabed for student use.

C. Summary.

Handouts: None

Problems: None

Solutions: None

NATURE OF X AND GAMMA RADIATION

DF040

DF040, NATURE OF X AND GAMMA RADIATION

I. Reference: ST 3-155, para 2.5d, 4.6c, 4.9b(3), and 4.9c(3).

II. Lesson Objectives and Notes:

A. Fundamentals of electromagnetic radiation.

B. Origin and production of X and gamma radiation.

Notes:

III. Handouts: None

IV. Problems: None

V. Solutions: None

TABLE OF ISOTOPES

DF050, TABLE OF ISOTOPES

I. References and Discussion.

A. References: Pam 25, pages 219 thru 409 (especially 221 thru 228).

B. NOTE: For the purposes of consistency within the Radiological Safety Course, when more than one value for a certain constant or characteristic is listed in the Table of Isotopes, the first listed value will be used.

C. The following is a discussion of the data shown in the Table of Isotopes for several specific isotopes illustrating what material may be obtained. The discussion is keyed to numbers shown overlayed on the table excerpt.

Isotope Z A	Half life	Type of decay (☢); % abundance, Mass excess (Δ≡M−A) MeV (C=0); Thermal neutron cross section (σ), barns	Class Identification; Genetic relationships	Major radiations: approximate energies (MeV) and intensities	Principal means of production
$_{29}Cu^{64}$ 1	12.80 h (FobJ55, RabE50) 2 12.88 h (SiL51); 12.87 h (WrtH57) 12.7 h (SchamRS1a) others (BiraG64, BatzK54a, KunD51 HubeO43a, HubeO44a JohnH52, FezlmM49 StraK53, EdwL52 MillDP49, VVu(S36a, HopH50, BeydJ57a PauA65, ZirH65)	☢ EC 43%, β^- 38%, β^+ 19% (NDS) 4 $(\beta^+ + EC)/\beta^-$ 1.6 (ReynJH50) 5 Δ −65.428 (MTW) 6	A 7 chem, n-capt (AmaE35) 8 excit (VVuoS36a) chem excit (DelL39)	β^- 0.573 max 9 β^+ 0.656 max 10 e^- 1.33 11 γ Ni X-rays, 0.511 (38%, γ±), 1.34 (0.5%) 12.	$Cu^{63}(n, \gamma)$ (HeyF37b, SerL47b) 13

$^{64}_{29}Cu$

1. Identification of radionuclide - Z number 29, chemical symbol Cu, and A number 64. Listed by Z numbers.

2. Half-life is 12.80 hours - use first listed as more correct. Reference behind tells where first stops and second starts.

3. Decay symbol means radioactive. If a percent sign was there, it would mean the nuclide is found in nature.

4. Types of decay - In a large sample 43% decays by electron capture, 38% by beta emissions, and 19% by positron emission.

5. Ratio of β^+ + EC decay to β^- decay - not used for our purposes.

6. Difference in A number (protons and neutrons) and actual mass number converted to million electron volts - not used for our purposes.

7. Certainty of nuclide - not used for our purposes.

8. Method of determination of the nuclide.

9. β^- max energy only - does not give the energy of all beta decays.

10. β^+ max energy only - does not give the energy of all positron decays.

11. Conversion electron energy - not used for our purposes.

12. Gamma energies - include X-rays as well as gamma emission. Ni (daughter) X-rays, annihilation radiation from B^+ decay - 0.511 (38% γ +) and normal gamma emission.

13. Method of production of $^{64}_{29}Cu$.

Isotope Z A	Half-life	Type of decay (γ); % abundance; Mass excess ($\Delta \equiv M-A$), MeV ($C^{12} \equiv 0$), Thermal neutron cross section (σ), barns	Class; Identification; Genetic relationships	Major radiations approximate energies (MeV) and intensities	Principal means of production
$_{32}Ge^{67}$ 1.	2. 18.7 m (RiccR59) 18.6 m (CogM65) 21 m (HopH50, VasiSS64) 19 m (AteA53) others (RiccR56)	γ β^+, EC (HopH50, RiccR59) 3 Δ -62.5 (MTW)	A chem, genet (HopH49) parent Ga^{67} (HopH49)	β^+ 3.1 max 4 γ 0.170 (105%, doublet), 0.511 (170%, $\gamma^{\pm}$), 0.84 (4%), 0.92 (7%), 1.48 (5%) 5 daughter radiations from Ga^{67}	$Zn^{64}(\alpha, n)$ (RiccR59) 6.

$^{67}_{32}Ge$

1. Nuclide in question.

2. Half-life of nuclide.

3. Types of decay - β^+, EC.

4. Positron max energy - 3.1 Mev.

5. Gamma energies:

   0.170 (105%, doublet) - reference page 223, last paragraph of major radiation column for explanation of doublet.

   0.511 (170%, $\gamma \pm$) annihilation radiation from positron.

   0.84 (4%), 0.92 (7%), 1.48 (5%).

6. Methods of production of $^{67}_{32}Ge$.

Isotope Z A	Half-life	Type of decay (☢); % abundance; Mass excess (Δ≡M−A), MeV (C¹²≡0); Thermal neutron cross section (σ), barns	Class; Identification; Genetic relationships	Major radiations, approximate energies (MeV) and intensities	Principal means of production
$_{45}Rh^{106}$ 1.	130 m (MayS58) 2. 133 m (SegO60a) others (BaroG55, NerW55)	☢ β^- (BaroG55) 3 Δ −86.3 (SegO60a, MTW)	A chem, excit (BaroG55, NerW55) genet energy levels (MayS58, SegO60a) not daughter Ru^{106} (BaroG55)	β^- 1.62 max (10%) 4. 1.1 max 5. γ 0.220 (18%, complex), 0.406 (18%), 0.451 (35%), 0.512 (88%), 0.616 (29%), 0.735 (41%), 0.82 (35%), 1.046 (25%), 1.128 (12%), 1.223 (17%), 1.56 (18%) 6	Pd^{108}(d, a) (BaroG55, MayS58, SegO60a) 7. Ag^{109}(n, a) (MayS58) 8

$^{106}_{45}Rh$

1. Radionuclide of interest.

2. Half-life of ^{106}Rh.

3. Type of decay.

4. Max energy beta from decay - 1.62 max (10%). It occurs only 10% of the time.

5. The next most energetic beta which occurs the majority of the time.

6. Gamma decay energies - refer to page 223 next to last paragraph of major radiation heading for explanation of complex.

7. Principle method of production.

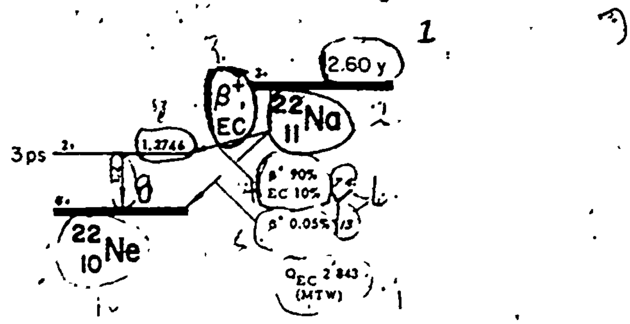
8. Another method of production.

DECAY SCHEMES

The decay schemes are drawn to the best of the author's ability to give a graphic representation of what occurs when decay of a radionuclide is accomplished.

The scheme itself has definite meaning from the lines involved. If the line slants to the right, it is negative (β^-) emission. If the line slants to the left, it is a positive (β^+, α) emission or electron capture (EC). If the line is vertical, it is a gamma or neutron emission. The parent nuclide is listed at the top and the distance between it and the bottom listing represents the energy lost by decay in going from the parent to the daughter nuclide. The lines with arrowheads represent decay emission. It starts at the end of the line and goes only as far as the daughter line, then another line from the point it stops represents another decay to complete the process.

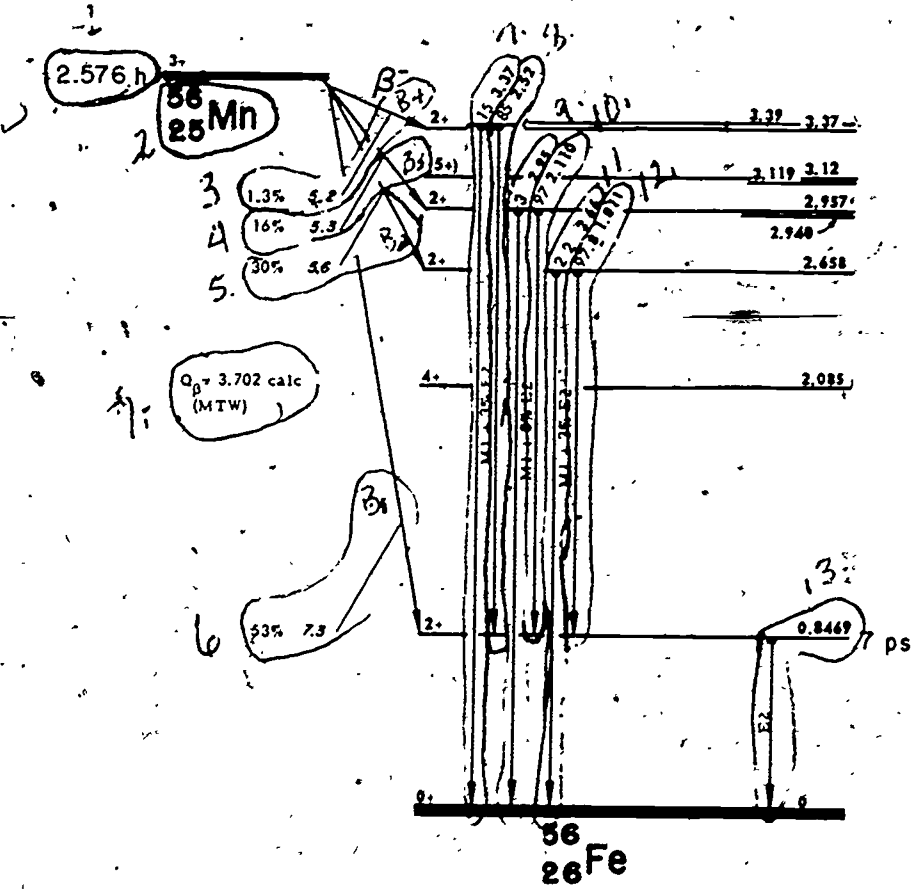
In an explanation of the decay scheme, only those points of interest will be explained. Further explanation of the scheme can be obtained on pages 227 and 228 of Pam 25.



^{22}Na (2.60 y):
I: 3, μ: +1.746 atomic beam (LindgI64)
β^+: β_2 0.545 (DaniH58a); 0.543 (HamiJ58a); 0.542 (MackP50a); 0.540 (WonC54);
mag spect
β_1 1.83 (I 0.06), β_2 0.540 (I 100) mag spect (WriB53)
others (GooW46, MorgK49, LeuH61, BranW64a, CharP65)
γ: γ_1 1.2746 semicond spect (RobiR65)
γ_1 (e/γ 6.7 x 10^{-6}) (NakY63, LeamR54)
others (MarlK65, SinP59, AlbuD49, AjzF55, GooW46)
$\beta\gamma(\theta)$: (GrabZ65, DaniH60a, SubB61b, StevD51, MullH65)
$\beta\gamma$polariz(θ): (StefR59, BloS62, AppH59, BhaS65, SchoH57)

Decay of $^{22}_{11}$Na.

1. Half-life of the parent nuclide.
2. Parent radionuclide.
3. Types of decay.
4. Percent of decay for upper line.
5. Percent of decay for lower line.
6. Hindrance factors - explained on page 228, second column. Of no importance to our calculations.
7. Energy of this line. From this line to the ground (daughter) states this much energy is emitted, since only one vertical line goes to the ground state (8). This is the gamma energy.
8. Gamma emission (energy 1.2746 Mev).
9. Total decay energy.
10. Daughter products.
11. Energy of positron in 4. Energy read from scheme bottom to top. There are two positron lines - the longest is β_1 and the next up is β_2.
12. Energy of positron is 5.



^{56}Mn (2.576 h):

I: 3, μ: +3.2403 atomic beam (LindgI64)

β^-: β_1 2.84 (47%), β_2 1.03 (34%), β_3 0.72 (18%), β_4 0.30 (1%) mag spect (HowD62a)

β_1 2.86 (60%), β_2 1.05 (25%), β_3 0.75 (15%) mag spect (ElliL43a)

β_1 2.81 (50%), β_2 1.04 (30%), β_3 0.65 (20%) mag spect (SiegK46a)

others (TownA41, VasiSS61, CharP65)

γ: γ_1 0.8468, γ_2 1.811, γ_3 2.110 cryst spect (ReidyJ65)

γ_1 0.845 (I_γ100), γ_2 1.81 (I_γ30), γ_3 2.12 (I_γ15.3), γ_4 2.52 (I_γ1.2), γ_5 2.65 (I_γ0.7), γ_6 2.95 (I_γ0.4), γ_7 3.39 (I_γ0.21) scint spect (CookCS58)

γ_2 ($e^\pm/\gamma$ 0.0006), γ_3 ($e^\pm/\gamma$ 0.0005) mag spect conv (SlaH52)

others (DagP59, GroshL57a, KieP59, BieJ64a, LeviN58, ElliL43a, SiegK46a, MunM55, KikS42, GermE53, MetF53c)

γγ(θ): (DagP59, LeviN58, MetF53c, MaliS59)

βγ(θ), βγpolariz(θ): (LobV62) nucl align: (DagP59, BaueR60a)

0.026 level of ^{56}Mn: $t_{1/2}$ 1.14×10^{-8} s delay coinc (DToiS61)
1.04×10^{-8} s delay coinc (BoniM64)
others (DAngN60)

0.109 level of ^{56}Mn: $t_{1/2}$ 5.1×10^{-9} s delay coinc (DToiS61, BoniM64)
others (DAngN60)

$^{56}_{25}Mn$

1. Half-life.

2. Parent radionuclide.

3. β^- (β_4) - occurs 1.3% of time. Look at bottom for beta energy.

4. β^- (β_3) - occurs 16% of time. Look at bottom for beta energy.

5. β^- (β_2) - occurs 30% of time. Look at bottom for beta energy.

6. β^- (β_1) - occurs 53% of time. Look at bottom for beta energy.

7. γ decay - 15% of all gamma from this level (1.3% of time) decays by emission of a 3.37 Mev gamma photon.

8. γ decay - 85% of all gamma from this level (1.3% of time) decays by emission of a 2.52 Mev gamma photon.

9. γ decay - 3% of all gamma from this level (16% of time) decays by emission of a 2.95 Mev gamma photon.

10. γ decay - 97% of all gamma from this level (16% of time) decays by emission of a 2.11 Mev gamma photon.

11. γ decay - 2.2% of all gamma from this level (30% of time) decays by emission of a 2.66 Mev gamma photon.

12. γ decay - 97.8% of all gamma from this level (30% of time) decays by emission of a 1.811 Mev gamma photon.

13. γ decay - gamma photon of 0.8469 emitted 53% of time.

14. Using first listed β_1 - the energy of (6) β_1 (β^-) is 2.84 Mev.

15. Using first listed β_2 - the energy of (5) β_2 (β^-) is 1.03 Mev.

16. Using first listed β_3 - the energy of (4) β_3 (β^-) is 0.72 Mev.

17. Using first listed β_4 - the energy of (3) β_4 (β^-) is 0.30 Mev.

II. Lesson Objectives and Notes:

Use of the Table of Isotopes.

III. Problems.

1. Using the table starting on page 51, Pam 25, list the more common isotopes of the following elements and give the mass of the heaviest isotope of each element.

	Z NUMBER AND ELEMENT NAME	NUMBER OF ISOTOPES	MASS OF HEAVIEST ISOTOPE
a.	11-Sodium	______	______
b.	24-Chronium	______	______
c.	60-Neodymium	______	______
d.	92-Uranium	______	______
e.	94-Plutonium	______	______
f.	36-Krypton	______	______

2. List the half-life of the following nuclides.

	NUCLIDE	HALF-LIFE
a.	${}^{3}_{1}H$	______
b.	${}^{14}_{6}C$	______
c.	${}^{24}_{11}Na$	______
d.	${}^{60}_{27}Co$	______
e.	${}^{137}_{55}Cs$	______
f.	${}^{235}_{92}U$	______
g.	${}^{82}_{35}Br$	______

3. What type(s) of particles would you expect from the decay of the following nuclides?

NUCLIDE	TYPE OF PARTICLE
a. $^{115}_{48}Cd$	______________
b. $^{124}_{53}I$	______________
c. $^{134}_{58}Ce$	______________
d. $^{241}_{95}Am$	______________
e. $^{212}_{83}Bi$	______________
f. $^{165}_{67}Ho$	______________
g. $^{63}_{28}Ni$	______________

4. After arriving at a new assignment, you decide to take an inventory of radioactive materials. One large lead container is found to have three bottles in it marked "1, 2, 3." A sign on the container states that it contains $^{90}_{38}Sr$-$^{90}_{39}Y$, $^{35}_{16}S$, $^{129}_{53}I$ in solution form; however, you can find no record of which nuclide is in which bottle. The nuclides are all beta emitters. You measure the beta energies and find the maximum beta energies are as follows. What nuclide is in each bottle?

BOTTLE	ENERGY	NUCLIDE
1	2.27	______________
2	0.150	______________
3	0.167	______________

5. Give the energy of the most energetic gamma photon from the following.

	ISOTOPE	GAMMA ENERGY IN MEV	PERCENT OCCURRENCE
a.	$^{117}_{51}Sb$	______	______
b.	$^{96}_{41}Nb$	______	______
c.	$^{79}_{33}As$	______	______
d.	$^{115}_{48}Cd$	______	______
e.	$^{60}_{27}Co$	______	______
f.	$^{70}_{33}As$	______	______
g.	$^{115}_{52}Te$	______	______
h.	$^{205}_{83}Bi$	______	______

6. You have been assigned to ship a large quantity of $^{57}_{27}Co$. In order to determine how thick the container wall must be to shield personnel from gamma radiation, you must know the most energetic of these gamma rays, which occur 3% of the time or greater.

The most energetic is ______.

7. List the types of particles emitted from the following nuclides, the percentage of the disintegrations which result in the particles, and maximum energies of the particles.

	NUCLIDE	TYPE OF PARTICLE	PERCENT	ENERGIES
EXAMPLE:	$^{64}_{29}Cu$	β^- β^+	38% 19%	0.573 Mev 0.656 Mev
a.	$^{80}_{35}Br$	________	________	________
b.	$^{101}_{46}Pd$	________	________	________
c.	$^{211}_{83}Bi$	________	________	________

8. What percentage of naturally occurring uranium ore is $^{235}_{92}U$?

ANSWER: ______________

9. Give the isotopes of the following element which are found in nature and the percentage abundance of each.

ELEMENT	ISOTOPES	ABUNDANCE
a. Oxygen		
b. Aluminum		
c. Zinc		
d. Uranium		

10. What is the energy of each of the beta particles given off in the decay of ^{131}I (decay scheme)? What percentage of the time is each particle given off?

RADIATION	ENERGY	PERCENT

11. According to Table I, Pam 25, for Manganese-56, what are the energies of all the indicated gamma transitions? What should be used for shielding purposes?

12. What gamma energies should be used for shielding in the decay of the following radionuclides (occur 3% of the time or greater)?

NUCLIDE		GAMMA ENERGY
a.	$^{34}_{17}Cl$	________
b.	$^{66}_{31}Ga$	________
c.	$^{119m}_{52}Te$	________
d.	$^{214}_{83}Bi$	________
e.	$^{141}_{56}Ba$	________
f.	$^{42}_{19}K$	________
g.	$^{60}_{27}Co$	________
h.	$^{59}_{26}Fe$	________
i.	$^{140}_{57}La$	________
j.	$^{192}_{77}Ir$	________

II. Solutions

	ATOMIC NUMBER AND ELEMENT NAME	NUMBER OF ISOTOPES	MASS OF HEAVIEST ISOTOPE
a.	11-Sodium	7	25.991740
b.	24-Chromium	[illegible]	55.940640
c.	60-Neodymium	13	150.923770
d.	92-Uranium	14	240.056633
e.	94-Plutonium	15	246.070120
f.	36-Krypton	17	89.919720

	NUCLIDE	HALF-LIFE
a.	$^{3}_{1}H$	12.262 years
b.	$^{14}_{6}C$	5730 years
c.	$^{24}_{11}Na$	14.96 hours
d.	$^{60}_{27}Co$	5.263 years
e.	^{137}Cs	30.0 years
f.	$^{235}_{92}U$	7.1×10^{8} years
g.	$^{82}_{35}Br$	35.34 hours

3.

	NUCLIDE	TYPE OF PARTICLE
a.	$^{115}_{48}Cd$	β^-
b.	$^{124}_{53}I$	β^+
c.	$^{134}_{58}Ce$	None (EC)
d.	$^{241}_{95}Am$	α
e.	$^{212}_{83}Bi$	β^-, α
f.	$^{165}_{67}Ho$	None (stable)
g.	$^{63}_{28}Ni$	β^-

4.

BOTTLE	ENERGY(Mev)	NUCLIDE
1	2.27	$^{90}_{38}Sr$ - $^{90}_{39}Y$
2	0.150	$^{129}_{53}I$
3	0.167	$^{35}_{16}S$

5.

	ISOTOPE	GAMMA ENERGY IN MEV	PERCENT OCCURRENCE
a.	$^{117}_{51}Sb$	0.511	5%
b.	$^{96}_{41}Nb$	1.2	21%
c.	$^{79}_{33}As$	0.89	1%
d.	$^{115}_{48}Cd$	0.53	26%
e.	$^{60}_{27}Co$	1.332	100%
f.	$^{70}_{33}As$	2.03	19%
g.	$^{115}_{52}Te$	1.58	6%
h.	$^{205}_{83}Bi$	1.906	2%

6. The most energetic is 0.692 Mev (0.14%). Considering those which occur 3% of the time or greater, the most energetic is 0.136 Mev (11%).

7.

	NUCLIDE	TYPE OF PARTICLE	PERCENT	ENERGY
a.	$^{80}_{35}Br$	β^- β^+	92% 2.6%	2.00 Mev 0.87 Mev
b.	$^{101}_{46}Pd$	β^+	2.5%	0.78 Mev
c.	$^{211}_{83}Bi$	α β^-	99+% 0.27%	6.62 Mev None listed

8. $^{235}_{92}U$ composes <u>0.7196</u> percent of naturally occurring uranium ore.

9.

	ELEMENT	ISOTOPE	ABUNDANCE
a.	Oxygen	^{16}O	99.759%
		^{17}O	0.037%
		^{18}O	0.204%
b.	Aluminum	^{27}Al	100%
c.	Zinc	^{64}Zn	48.89%
		^{66}Zn	27.81%
		^{67}Zn	4.11%
		^{68}Zn	18.56%
		^{70}Zn	0.62%
d.	Uranium	^{234}U	0.0057%
		^{235}U	0.7196%
		^{238}U	99.276%

10.

RADIATION	ENERGY	PERCENT
β_1	0.81	0.6%
β_2	0.608	90.4%
β_3	0.33	0.5%
β_4	0.25	6.9%
β_5	Not listed	1.6%

11. Energies from Table I, Pam 25, are:

0.847, 1.811, 2.110.

For shielding purposes, the maximum gamma energy occurring 3% of the time or greater is used.

The first, 0.847, occurs 99%. The second, 1.811, occurs 29%, and the third, 2.110, occurs 15%.

The energy used for shielding purposes is 2.11 Mev.

12.

NUCLIDE		GAMMA ENERGY (Mev)
a.	$^{34}_{17}Cl$	0.511
b.	$^{66}_{31}Ga$	4.3
c.	$^{119m}_{52}Te$	2.09
d.	$^{214}_{83}Bi$	2.204
e.	$^{141}_{56}Ba$	1.65
f.	$^{42}_{19}K$	1.524
g.	$^{60}_{27}Co$	1.332
h.	$^{59}_{26}Fe$	1.292
i.	$^{140}_{57}La$	2.53
j.	$^{192}_{77}Ir$	0.612

SHIELDING OF CHARGED PARTICLES

DF060, SHIELDING OF CHARGED PARTICLES

I. References: ST 3-155, Chapter 4, paragraph 4.1, 4.2, 4.5, 4.6, 4.7, 4.9.

II. Lesson Objectives and Notes:

A. Mechanism of absorption of charged particles.

B. Range of beta particles.

Notes:

III. Handouts: None

IV. Problems.

A. Class and home problems.

1. From the figure on page 122, Pam 25, obtain the following values (in inches).

   a. The range in air of a 1 Mev beta particle.

   b. The range in water of a 4 Mev beta particle.

   c. The range in aluminum of a 0.3 Mev beta particle.

   d. The range in lead of a 1.7 Mev beta particle.

2. From the figure, page 122, Pam 25, find the range (in inches) of a 3 Mev beta particle in each material listed below.

   a. Air

   b. Water

   c. Aluminum

   d. Lead

3. Convert each range obtained in problem 2 into centimeters (1 inch = 2.54 centimeters).

4. From figure, page 123, Pam 25, what is the range in mg/cm^2 of a 1 Mev beta particle? What is this range expressed in centimenters of aluminum?

5. Based on figure, page 123, Pam 25, what is the range in centimeters of an 8 Mev beta particle in copper?

6. Based on the figure, page 123, Pam 25, what is the range in centimeters of a 0.7 Mev beta particle in gold?

7. In a laboratory experiment the maximum range of beta particles from a source was found to be 0.25 cm in aluminum. What is the maximum energy of the beta particles?

8. A lead shield is bombarded with beta radiation with the maximum range being 0.06 cm. What is the maximum energy of the beta particles?

V. Solutions to problems.

A. Solutions to class problems.

1. From page 122, Pam 25 -

a. The range in air of a 1 Mev beta particle is 120 inches.

b. The range in water of a 4 Mev beta particle is 0.95 inch.

c. The range in aluminum of a 0.3 Mev beta particle is 0.011 inch.

d. The range in lead of a 1.7 Mev beta particle is 0.625 inch.

2. From page 122, Pam 25, range of 3 Mev beta particle -

a. In air - 520 inches.

b. In water - 0.67 inch

c. In aluminum - 0.25 inch.

d. In lead - 0.055 inch.

3. Conversion of ranges in problem into centimeters:

a. 520 inches = (520)(2.54) centimeters

= 1320 cm

b. 0.67 inches = 1.70 cm

c. 0.25 inches = 0.635 cm

d. 0.055 inches = 0.1398 = 0.14 cm

4. From page 123, Pam 25 -

Range of 1 Mev beta particle = 400 mg/cm^2.

In aluminum: $X = \frac{R}{\rho}$

ρ = 2.699 gm/cm^3 (page 65)

ρ = 2699 mg/cm^3

then $X = \frac{400}{2699}$ = 0.148 cm.

5. From page 123, Pam 25.

For 8 Mev beta particle $R = 4150 \text{ mg/cm}^2$

From page 65, Pam 25 $\rho = 8.94 \text{ gm/cm}^3 = 8940 \text{ mg/cm}^3$

$$X = \frac{R}{\rho} = \frac{4200}{8940} = \underline{\underline{0.464 \text{ cm}}}$$

6. Based on page 123, Pam 25 -

For 0.7 Mev beta particle $R = 250 \text{ mg/cm}^2$

From page 65, Pam 25 -

ρ of gold $= 19.32 \text{ gm/cm}^3 = 19{,}320 \text{ mg/cm}^3$

$$X = \frac{R}{\rho} = \frac{250}{19{,}320} = \underline{\underline{0.0129 \text{ cm}}}$$

7. Max X = 0.25 cm in aluminum.

From page 65, Pam 25 -

ρ for Al $= 2699 \text{ mg/cm}^3$

$$R = X\rho = 0.25\,(2699) = \underline{\underline{675 \text{ mg/cm}^2}}$$

From page 123, Pam 25 -

Max energy of beta particle = $\underline{\underline{1.5 \text{ Mev}}}$.

8. Max X = 0.06 cm in lead.

From page 65, Pam 25 -

$\rho = 11{,}350 \text{ mg/cm}^3$

$$R = X\rho = 0.06\,(11{,}350) = \underline{\underline{681 \text{ mg/cm}^2}}$$

From page 123, Pam 25 -

Max energy = $\underline{\underline{1.51 \text{ Mev}}}$

SPECIAL HAZARDS

DF070

DF070, SPECIAL HAZARDS

I. A. References: TM 3-220, para 100-105; Pam 25, pages 194-203, 206-209.

B. Discussion.

1. Radioactive Materials.

a. General.

The greatest hazard to the worker in the field of radioactivity lies in the accidental entry of radioactive material into the worker's body. The mode of entry may be by inhalation of airborne dusts or aerosols, ingestion, accidental injection, or entry through an open wound. Regardless of the mode of entry, a small amount of internally deposited radioisotope may present a considerable hazard whereas the same amount would be unobjectionable if outside the body. Because of their chemical or nuclear properties, some commonly used radionuclides are more hazardous than others.

The chemical or physical form, the chemical properties and/or the nuclear characteristics of many elements and compounds offer potentially dangerous conditions with which the radiation protection or safety officer will have to contend. Some hazardous non-radioactive materials are commonly used in the radiation work area which may be overlooked because of their non-radioactivity. The special hazards or special hazard situations which could result from using special hazard materials require the radiation protection or safety officer to recognize the potential hazard, establish safety procedures to offset the potentiality of the hazard, and be prepared to institute emergency procedures if preventive actions fail. This discussion is presented to make the reader aware of some of the special hazard materials encountered in many radiation work areas.

b. Definitions.

Special Hazard - A hazard or potential hazard presented by a radionuclide or radioactive material apart from the external radiation hazard common to all radioactive materials.

Special Hazard Material - A radionuclide or radioactive compound which, because of its intrinsic characteristics, presents a special hazard.

Special Hazard Situation - A procedure, operation, or situation which, because of the intrinsic characteristics of the radionuclide involved, presents hazards not encountered when working with other radioactive materials.

c. Special Hazard Materials.

(1) Tritium.

(a) General. After the discovery of deuterium in 1931, much effort was expended in searching for a hydrogen isotope of mass number 3. Exhaustive electrolysis of highly concentrated deuterium oxide samples gave residues in which tritium was detected, the quantities of the material being such that a natural ratio of 10^{-18} atoms of tritium per atom of light hydrogen ($^{1}_{1}H$) was suggested in 1940. However, the ratio 10^{-18} being so low, the existence of natural tritium is often disregarded.

(b) Tritium production. Natural tritium is believed to be formed by neutron bombardment of atmospheric nitrogen according to the equation

$$^{14}_{7}N + ^{1}_{0}n \rightarrow ^{12}_{6}C + ^{3}_{1}T + Q$$

The necessary neutrons result from the action of cosmic radiation on atmospheric gases.

Tritium was first prepared artifically by Lord Rutherford, Marcus L. E. Oliphant and Harteck in 1935 by the bombardment of deuterophosphoric acid with fast deuterons. Deuterium compounds bombarded with high energy deuterons produce tritium and light hydrogen according to the equation

$$^{2}_{1}D + ^{2}_{1}D \rightarrow ^{3}_{1}T + ^{1}_{1}H + Q$$

Helium is also produced according to the equation

$$^{2}_{1}D + ^{2}_{1}D \rightarrow ^{3}_{2}He + ^{1}_{0}n + Q$$

Tritium has also been obtained by the reaction of slow neutrons on lithium in particle accelerators or nuclear reactors according to the equation

$$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{3}_{1}T + ^{4}_{2}He + Q$$

Other possibilities of production are from deuteron bombardment of beryllium.

$$^{9}_{4}Be + ^{2}_{1}D \rightarrow ^{3}_{1}T + ^{8}_{4}Be + Q$$

or,

$$^{9}_{4}Be + ^{2}_{1}D \rightarrow ^{3}_{1}T + 2\,^{4}_{2}He + Q$$

and a few related processes. The reactions Be (d, 2α) T and Li (n, α) T are useful in the preparation of tritium in sizeable quantities.

(c) Characteristics. Tritium is the only known radioisotope of hydrogen. The following symbols are used to indicate tritium: $^{3}_{1}H$, $^{3}_{1}T$, or T. As a gas, it is referred to as T_2 or $^{3}H_2$.

Tritium has a half-life of 12.262 years and emits beta particles of 18 Kev energy. This is one of the least energetic beta particles known. Undiluted tritium gas has an activity of 2.6 curies/cc STP or 9.8×10^3 curies/gram. Pure tritiated water has an activity of about 2.7×10^3 curies/gram. Since it is an isotope of hydrogen, tritium has the same chemical properties as hydrogen. It is explosive in the proper concentrations. It diffuses rapidly and strongly adsorbs onto and absorbs into all surfaces. Tritium undergoes isotopic exchange with hydrogen combined in molecules, especially water and hydrocarbons. Under proper conditions, it combines directly with most of the lighter and many of the heavier elements to produce a hydride of the element with which it combines. Some of these reactions can be very violent, yielding high temperatures.

(d) Uses. Tritium may be used in nuclear weapons. It is also finding extensive use in both civilian and military applications other than weapons. Tritium is rapidly replacing radium as the radioactive component in luminous paint used on compass and watch dials and sighting mechanisms. Some detecting elements used on gas chromatographs and accelerator targets for neutron sources have tritium as a component.

Tritium measurements are also used in dating experiments. Determination whether an underground reservoir is static or not, circulation in the Great Lakes and the actual age of a wine have been accomplished using tritium counting techniques.

TABLE I
TRITIUM

ELEMENT	TYPE OF DECAY	RADIO HALF-LIFE	PROPERTIES/USES
Tritium	β^-	12.3 years	1. Colorless, odorless, tasteless gas.
^3_1T; ^3_1H	18 Kev		2. Diffuses through materials.
			3. Absorbed by metals.
			4. Forms metal hydrides.
			5. Replaces hydrogen in hydrogen compounds.
			6. Constituent of luminescent paints.
			7. Tritium bearing weapons.

TRITIUM OXIDE

COMPOUND	TYPE OF DECAY	RADIO HALF-LIFE	PROPERTIES/USES
Tritium Oxide	β^-	12.3 years	1. In equilibrium in replacement reactions.
HTO; T_2O			Example: $H_2O + T_2 \rightleftarrows HTO + HT$
			2. More easily absorbed in the body than T_2.

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(e) Hazards. Tritium gas, or vapor, quickly disperses into the atmosphere and adsorbs strongly onto many surfaces or even penetrates deeply into many construction materials from which outgassing may occur later. Complete penetration of rubber hoses and thin plastics can occur in a few hours. Substantial non-volatile transfer of tritium from contaminated surfaces to skin by direct contact has been demonstrated. Since tritium radioactivity on the contaminated surfaces is not necessarily detectable by gas-flow monitoring methods, this route of entry of tritium into body tissue must be considered an unrecognized, potential hazard, where the handling of surfaces exposed to high levels of tritium is concerned. The possibility of contact-transferred tritium in skin, its chemical form and location within the skin, and the exact radioactivity content of the contaminated surfaces are particular problems.

The radiation hazard to personnel from an accidental release of tritium gas increases with time because of the conversion of tritium to tritium oxide. The latter is much more rapidly absorbed by the body because of its greater solubility. Tritium gas is absorbed equally through the lungs and skin after which ^3_1T atomic replacement of the ^1_1H atom in H_2O will take place. In addition, THO or T_2O can be inhaled or absorbed through the skin. Consequently, the tritium hazard is to the whole body, with the body fluid (water) the critical item. Above normal quantities of liquids during the first 10 hours after an exposure should not be consumed unless prescribed by a physician.

The main hazard of tritium is that it is extremely difficult to detect and therefore may be present in an area without the knowledge of the personnel present.

TABLE II

SPECIAL HAZARDS
TRITIUM

ELEMENT OR COMPOUND	CRITICAL ORGAN	SAMPLE OF CHOICE	BIOLOGICAL HALF-LIFE	SPECIAL HAZARDS
Tritium	Whole body	Urine	12 days	1. Difficult to detect. 2. Diffusion through and into materials. 3. Skin contact transfer. 4. Hydrogen isotope explosive. 5. Outgassing
Tritium Oxide	Whole body	Urine	12 days	1. Readily absorbed into the body. 2. Difficult to detect.

(f) Protective Measures. The hazardous effects of tritium can be minimized by aeration of a confined space or flushing the area under vacuum with helium or hydrogen if necessary (control of explosive hazard is required however). The Savannah River Plant of the E. I. du Pont de Nemours and Co., which uses large amounts of tritium, makes extensive use of walk-in hood facilities to minimize the potential hazards of tritium. Buildings in which large numbers of tritium bearing devices are stored should have adequate ventilation to prevent a tritium buildup in case the devices leak. Since T_2 goes through filter masks, breathing apparatus with self contained air supplies are required to reduce the exposure dose. Rubber and plastic gloves with air supplied suits will further reduce the exposure dose. Even in this case, the equipment should be replaced every 30 minutes because of the T_2 penetration of rubber hoses, etc..

(g) Decontamination.

Tritium diffuses very quickly and unless released in a closed area will present little or no hazard. If an enclosed area is capable of being flushed with air, then it is possible to reduce the hazard and occupy the building after the ^3T has been flushed out. Objects in the area exposed to tritium may absorb the gas and should therefore be disposed of as radioactive waste. If the material is needed, degassing under a vacuum by flushing with helium or hydrogen may be done. However, the certainty of complete decontamination to a safe level is low.

(2) Uranium.

(a) General. All nuclear weapons contain a certain amount of fissionable material, either uranium or plutonium or both. Nuclear accident/incident control personnel as well as radiological protection officers are concerned with the special hazards associated with uranium.

(b) Characteristics. Uranium-233 is an alpha (4.8 Mev) and gamma (0.097 Mev) emitter. Uranium-234 is an alpha (~4.8 Mev) emitter. Uranium-235 is an alpha (~4.6 Mev) and gamma (0.18 Mev) emitter, and Uranium-238 is an alpha (~4.2 Mev) emitter.

Uranium metal reacts readily with oxygen in the air to produce small particles of insoluble oxide which can become airborne under proper conditions.

The permissible levels for soluble compounds and the level for insoluble compounds in air are based on chemical toxicity, while the permissible body level for insoluble compounds is based on radiotoxicity.

The high chemical toxicity of uranium and its salts is largely shown in kidney damage, and acute necrotic arterial lesions. The rapid passage of soluble uranium compounds through the body tends to allow relatively large amounts to be taken in. The highly toxic effect of insoluble compounds is largely due to lung irradiation by inhaled particles. Because of their small solubility, absorption of the oxide by the gastrointestinal system is very low. Penetration of the unbroken skin is impossible and although the material may enter where the skin is broken, it will be localized at the point of access. It may be cleansed away, even at some later time, without appreciable transfer in the bloodstream or other body tissues having occurred because of low solubility.

(c) Uses. As previously stated, uranium is found in some nuclear weapons. It has also been used on source check plates for laboratory and field use.

(d) Special Hazards. The primary special hazards presented by uranium are the high chemical toxicity of its soluble compounds and its alpha irradiation of lung tissues if airborne particles are inhaled.

Other hazards include entrance of particles of uranium through the broken skin; ingestion of insoluble uranium or uranium compounds which emit alpha particles to cause damage to the intestines; and, a fire hazard resulting if solid or dust forms of uranium metal are exposed to intense heat or flame.

TABLE III

URANIUM

ELEMENT OR COMPOUND	TYPE OF DECAY	RADIO HALF-LIFE	PROPERTIES/USES
^{233}U	α 4.8 Mev α~ 0.1 Mev	1.62×10^5 years	1. Metal readily reacts with oxygen in the air to give an oxide.
^{234}U	α~ 4.8 Mev	2.47×10^5 years	2. Constituent of some weapons.
^{235}U	α~ 4.6 Mev γ 0.18 Mev	7.1×10^8 years	
^{238}U	α~ 4.2 Mev	4.51×10^9 years	

SPECIAL HAZARDS

ELEMENT	CRITICAL ORGAN	SAMPLE OF CHOICE	BIOLOGICAL HALF-LIFE	SPECIAL HAZARDS
Uranium	Kidney Lungs	Urine	120 days	1. Soluble compounds have high chemical toxicity. 2. Insoluble compounds irradiate intestines. 3. Fire hazard - metal.

(e) Protective Measures. Respiratory protection must be provided to personnel who are likely to enter an airborne concentration of uranium compounds which exceeds maximum permissible standards as established by Title 10, Part 20, CFR. Gloves should be used by personnel who handle uranium sources, especially if open wounds are susceptible to contamination.

(f) Decontamination. The reader is referred to TM 3-220 for decontamination considerations for uranium. The general discussion for preplanning actions to be taken in the event of an accident as applied to radium are applicable also to uranium.

(3) Plutonium.

(a) General. Plutonium was the first of the man-made elements to be produced in large enough amounts to be visible. It has 15 known isotopes ranging in atomic weight from 232 to 246 and all isotopes are radioactive. Plutonium-239 is the most commonly used material. It can be formed in a nuclear reactor from natural uranium according to the formula

$$^{238}_{92}U + {}^{1}_{0}n \longrightarrow {}^{239}_{92}U \xrightarrow[23.5m]{\beta} {}^{239}_{93}Np \xrightarrow[2.35d]{\beta} {}^{239}_{94}Pu$$

(b) Characteristics. Plutonium-239 is primarily an alpha emitter, giving off a very high energy alpha particle of about 5.2 Mev. A low energy (0.05 Mev) gamma photon is emitted 0.02% of the time. It has a half-life of 2.4×10^4 years.

Plutonium is a highly reactive metal. It readily combines with the oxygen of ordinary humid air to form a finely powdered oxide. Increasing temperatures increase the oxidation rate. It is readily dissolved in concentrated hydrochloric, hydroiodic, and perchloric acids.

(c) Uses. The first atomic bomb, exploded in the desert 60 miles from Alamogordo, New Mexico, on July 16, 1945, contained plutonium. Sixteen months later, it was first used in the Clementine nuclear reactor. Since that time it has found ever increasing uses in reactor fuels. It has provided a long lived and stable neutron source. It can also be used to produce transplutonium elements by irradiation in the intense flux of a reactor. The most common use encountered by radiological protection officers is in calibration and/or check sources such as the AN/UDM-6 and the TS-123Q( ).

(d) Special Hazards. The permissive levels for plutonium are the lowest for any of the radioactive elements. Plutonium concentrates directly in the blood forming sections of the bone rather than in the more uniform distribution shown by other heavy elements, such as radium. A principal hazard is associated with the inhalation of plutonium compounds and subsequent irradiation of the lungs.

The ingestion hazard of the oxide is minimal due to its low solubility, but entry of the powdered oxide through cuts or skin abrasions is a severe hazard.

Plutonium metal has been known to burn spontaneously in atmospheres with more than normal concetrations of oxygen and when coming into contact with petroleum products.

TABLE IV

PLUTONIUM

ELEMENT OR COMPOUND	TYPE OF DECAY	RADIO HALF-LIFE	PROPERTIES/USES
Plutonium ^{239}Pu	α~5.2 Mev γ~0.05 Mev	2.4×10^4 yr	1. Metal reacts readily with oxygen in air to give oxide. 2. Found in some weapons. 3. Used in AN/UDM-6 Calibrator.

SPECIAL HAZARDS

ELEMENT OR COMPOUND	CRITICAL ORGAN	SAMPLE OF CHOICE	BIOLOGICAL HALF-LIFE	SPECIAL HAZARDS
Plutonium	Bone (sol) Lung (insol)	Urine	200 years	1. Concentrates directly in blood forming section of the bone. 2. Severe hazard if entry through broken skin. 3. Fire hazard - metal.

(e) Protective Measures. Because of the severely toxic nature of plutonium, the maximum permissible body burdens are set very low and correspondingly, the maximum permissible concentrations are set equally low. Strict control of radioactive contamination is imperative in a plutonium operation. Cleanliness of the work area, protective clothing and respiration are required when working with loose plutonium. Check sources or calibration plates must be handled with extreme caution to avoid flaking or scratching the surface. Wipe tests must be performed periodically and hauling tools or gloves should be used when transporting a source.

(f) Decontamination. The reader is referred to TM 3-220 for decontamination procedures and techniques. In addition to the procedures listed therein, as a last resort, plutonium may be removed from the skin using a potassium permanganate (6.4 gm/100 ml) and 1% sulfuric acid solution (0.2N), followed by brushing (not longer than 2 minutes), rinsing, and rewashing with 5% sodium acid sulfite solution (10 gm Na HSO_3/200 ml H_2O) (not longer than 2 minutes). The procedure may be repeated several times as long as the 2 minute maximum washing time in each step is observed.

(4) Strontium-90 - Yttrium-90.

(a) General. Use of ^{90}Sr-^{90}Y is becoming more common as attempts have been made to produce portable calibration devices that require less and lighter shielding than conventional gamma radiation sources. An example is the Army's TS-784A/PD Radiac Calibrator.

(b) Characteristics. Strontium-90 is a pale yellow, soft metal found in equilibrium with its daughter product, Yttrium-90. A source of pure ^{90}Sr will reach an equilibrium with its daughter, ^{90}Y, in about 14 days and thereafter, the quantity of Yttrium, measured in curies, will be the same as the quantity of strontium and will follow its decay.

Strontium-90 emits beta radiation of about 0.55 Mev. Its half-life is 27.7 years. Yttrium-90 emits beta radiation of about 2.27 Mev. Its half-life is 64 hours.

(c) Uses. As calibration sources, ^{90}Sr-^{90}Y beta (particulate) radiations interact with various shielding materials to produce bremsstrahlung (energy) radiation for calibration of gamma detecting/measuring radiac meters.

(d) Special Hazards. These isotopes are among the most hazardous handled in laboratory and plant operations. Strontium-90 is a bone seeker. It will replace the calcium in the bone and act as a source of internal radiation to the blood forming tissues.

Strontium and Yttrium present a moderate fire hazard in the form of dust when exposed to flame. Strontium-90 metal is highly dangerous if it comes into contact with water or steam. Like sodium metal, it will release heat and hydrogen gas and may cause an explosion.

(e) Protective Measures. Workers using Sr-Y sources must be cautioned on the special hazards of the material with which they are working. Working areas must be clean and free of oxidizing or caustic agents which could possibly be transferred to contact the source. Immersion and other wet or smear techniques are preferred for metallic or chloride sources. Gloves and protective eye goggles or glasses should be worn to protect the hands and eyes from possible damage due to the caustic nature of strontium oxides and hydroxides. The goggles or glasses will also provide retinal protection from the high energy beta particles released by Yttrium-90.

(f) Decontamination. The reader is referred to TM 3-220 for decontamination techniques and procedures. The general preplanning techniques discussed previously for radium should be applied also to strontium-yttrium sources.

(5) Polonium.

Polonium is another metal coming into more use as a radiation source in the isotopic form Polonium-210.

(a) Characteristics and Hazards. Polonium-210 is an alpha (5.3 Mev) and gamma (0.80 Mev) emitter. Polonium salts which are soluble will concentrate in the spleen if the source enters the body. Insoluble salts are sources of alpha radiation to the lungs and the intestinal tract if inhaled or ingested. Extreme care must be taken to contain this material because it may become airborne or be ingested very rapidly. The primary special hazard presented by Polonium-210 is that it is difficult to handle without contaminating surrounding areas.

(b) Protective Measures. Extreme caution must be used when handling this material. The high energy of the alpha particle emitted by ^{210}Po makes it as hazardous as plutonium as an alpha emitter. In addition to the precautions taken when using plutonium users of polonium should consider the use of glove boxes or similar devices to assure the containment of the source.

(c) Decontamination. The general principles of decontamination should be applied to ^{210}Po decontamination. Circulating air systems are of particular concern in preventing the spread of the contaminant.

(6) Cesium.

(a) General. Because Cesium-137 is not a bone seeker and has a very long half-life (30 years), it has been used as a replacement for shorter lived Cobalt-60 or hazardous Radium-226. (An example is the AN/UDM-1A Radiac Calibrator, a ^{137}Cs source, which has replaced the AN/UDM-1 Radiac Calibrator, a ^{60}Co source.)

(b) Cesium-137 is a beta emitter (0.51 Mev (93.5%) and 1.2 Mev (6.5%) in equilibrium with its daughter Barium-137m, a gamma emitter (0.66 Mev)). Cesium-137 sources are usually produced from powdered cesium sulphate and then used in sealed containers. Other salts of cesium have been used in the past, however, and the stability of the source must be carefully evaluated before use. Cesium chlorates and bromates can decompose with evaluation of oxygen producing an eruption hazard. Cesium chloride and bromide are hygroscopic salts. A leaking source could produce widespread contamination because of this property. Cesium metal can ignite spontaneously (as sodium) on contact with water.

(c) Protective Measures. Users of ^{137}Cs should know what salt of cesium is contained in their sources. Plans of use, leak testing, etc., should be made so as to reduce the hazardous potential of the source involved.

(d) Decontamination. The reader is referred to TM 3-220 for specific decontamination techniques and procedures.

(7) Other Commonly Used Radionuclides.

(a) Artificial isotope Iodine-131 is used widely in medical circles for diagnostic and therapeutic purposes because the element is concentrated by the body in the thyroid gland. Because of the relative smallness of this organ, the permissible body level is quite low. Frequently there is a tendency by doctors to overdose. This tendency must be avoided whenever possible.

(b) Cobalt-60 is more likely an external than an internal hazard. Metallic Cobalt-60 is commonly used in sealed gamma sources. Many sealed sources leak as a result of electrolytic action between cobalt and the container. The result is often a soluble cobalt salt which creeps and spreads. Frequent leak testing of capsules containing metallic cobalt is desirable. Specific decontamination procedures and techniques are discussed in TM 3-220.

(8) Commonly Used Non-radionuclides.

(a) General. Because of their nuclear properties, beryllium and lead are often used in conjunction with radionuclides. These materials are so commonly used that their intrinsic hazards are often neglected. The emphasis placed on radiation protection associated with the use of the radionuclide increases the possibility of neglect. Radiological protection officers should establish and enforce safety procedures to reduce the hazards presented by beryllium and lead.

(b) Beryllium. As a pure metal or part of a compound, beryllium is toxic. It may cause death or permanent injury after very short exposures to small quantities when taken into the body by inhalation or ingestion. Inhalation is the most significant means of entry into the body. Beryllium can cause berylliosus which is a respiratory disease, similar to pneumonia.

(c) Lead and Lead Compounds. Pure lead and most of its compounds are toxic. Lead concentrates in the kidneys and bone where it is liberated into the bloodstream causing anemia. Lead poisoning is one of the most common of occupational diseases. The lead must enter the body or tissues, otherwise, no exposure can be said to exist. Modes of entry are:

1. By inhalation of dusts, fumes, mists, and vapors.

2. By ingestion of lead compounds trapped in upper respiratory tract or introduced into the mouth on food, tobacco, fingers, or other objects.

3. Through the skin - in the case of organic lead compounds.

Large percentages of lead entering the body by ingestion are excreted and for this reason, large amounts and long exposure are necessary to cause poisoning by this route. On the other hand, when lead is inhaled, absorption takes place easily and symptoms develop more quickly.

Lead is a cumulative poison. Increasing amounts build up in the body and eventually a point is reached where symptoms and disability occur.

Lead carbonate, monoxide, and sulphate are considered the more hazardous compounds and also more toxic than lead metal.

In any case, inhalation of vapor, fumes, and dusts presents the most serious hazard - whether metal or compound is encountered.

TABLE V

OTHER SPECIAL HAZARD MATERIALS

ELEMENT OR COMPOUND	TYPE OF DECAY	RADIO HALF-LIFE	CRITICAL ORGAN	BIOLOGICAL HALF-LIFE	HAZARDS
Strontium-90	β0.55 Mev	27.7 yr	Bone	52 years	*Replaces calcium in the bone. Fire hazard. Reacts with water.
Yttrium-90	β2.27 Mev	64 hr	-		Insoluble compounds will irradiate lungs. In equilibrium with ^{90}Sr.
Polonium-210	α5.3 Mev γ0.8 Mev	138 days	Spleen	60 days	Alpha emitter. Difficult to handle without contamination.
Cesium-137 Bromide Chloride	β0.51 Mev γ0.7 Mev	30 yrs	Whole body (sol)	70 days	Metal reacts violently with water. Soluble salts hygroscopic and easily dispersed.
Iodine-131	β0.61 Mev γ0.64 Mev	8 days	Thyroid	138 days	Overdose.
Beryllium	None	-	Lungs	-	Toxic metal.
Lead and Compounds	None	-	Bone Kidney	-	Severe inhalation hazard. Chemically toxic to the body.

d. Medical Aspects of Special Hazard Materials.

(1) Evaluation of Internal Exposure.

If personnel are suspected of having been exposed internally to special hazard materials, confirmation and an evaluation of dose received are required. Because the characteristics of special hazard materials vary, and because they concentrate in specific critical organs of the body, the techniques of determining exposure vary. Table VI below indicates the sample of choice for determining internal exposure.

Table VI

SAMPLE DETERMINATION OF INTERNAL EXPOSURE

ISOTOPE	SAMPLE OF CHOICE	REMARKS
^3H; HTO 1	Urine	
Radium	Feces	
Radon	Breath and Urine	
Thoron	Breath and Urine	
Uranium	Urine	
Plutonium	Urine and Feces	Collect as pooled 24 hour samples; save feces for 3-5 days.
Sr-Y	Urine	Preserve urine with 1 mg/ml sulfonic
Polonium	Urine	acid; store at 3^oC; at least 100 ml needed.

Should leakage and ingestion occur, the body dose cannot be calculated by simply integrating the dose rate from the initial dose over a convenient period, since some or all of the element or compound in question will have been removed from the body by execretion before it could decay.

In order to take this into account, a modified $t_{\frac{1}{2}}$ is introduced. This is the effective half-life ($t_{\frac{1}{2}}$) and is connected with the physical half-life (i.e., $t_{\frac{1}{2}}$ by radioactive decay only) and the biological half-life (i.e., half-life by excretion alone) by the expression

$$\frac{1}{t_{\frac{1}{2}}\ \mathrm{eff}} = \frac{1}{t_{\frac{1}{2}}\ \mathrm{phy}} + \frac{1}{t_{\frac{1}{2}}\ \mathrm{bio}}$$

where

$t_{\frac{1}{2}}$ eff is the effective half-life.

$t_{\frac{1}{2}}$ phy is the physical half-life, and

$t_{\frac{1}{2}}$ bio is the biological half-life.

This formula is applicable to all ingested sources. Table VII gives useful data for possible accidental exposure or contamination to the special hazard materials previously discussed. The table combines information from Table I of NBS Handbook 69, and Table XII of Report of Committee II, International Commission on Radiological Protection on Permissible Dose for Internal Radiation (1959 revision) and is extracted in part from Table 18.82 of NRC Handbook, Medical Aspects of Radiation Accidents.

Table VII

RADIONUCLIDES THAT MAY BE ENCOUNTERED ON ACCIDENTS

RADIONUCLIDE AND TYPE OF DECAY	ORGAN OF REFERENCE	MAXIMUM PERMISSIBLE BODY BURDENS (μci)	PHYSICAL HALF-LIFE ($t_{\frac{1}{2}}$ phy) (days)	BIOLOGICAL HALF-LIFE ($t_{\frac{1}{2}}$ bio) (days)	EFFECTIVE HALF-LIFE ($t_{\frac{1}{2}}$ eff) (days)
$^{3}_{1}H$, HTO, T_2O	Body Tissue	10^3	4.5×10^3		
(β^-) (sol)	Total Body	2×10^3 (100%)*		12	12
$^{60}_{27}Co$ (β,γ)	GI(LLI)**		1.9×10^3	18/24	
(sol)	Total Body	10			9.5
(insol)	Lung GI(LLI)				

Table VII (cont)

RADIONUCLIDE AND TYPE OF DECAY	ORGAN OF REFERENCE	MAXIMUM PERMISSIBLE BODY BURDENS (μci)	PHYSICAL HALF-LIFE ($t_{\frac{1}{2}}$ phy) (days)	BIOLOGICAL HALF-LIFE ($t_{\frac{1}{2}}$ bio) (days)	EFFECTIVE HALF-LIFE ($t_{\frac{1}{2}}$ eff) (days)
$^{90}_{38}Sr$ (β^-)	Bone	2 (95%)	10^4	1.8×10^4	
(sol)	Total Body	20			5,700
(insol)	Lung				
	GT(LLI)				
$^{90}_{38}Y$ (β^-)	GI(LLI)		2.68	18/24	
(sol)	Bone	3			
	Total Body	20			2.68
(insol)	GI(LLI)				
	Lung				
$^{131}_{53}I$ (β^-, γ, e^-)	Thyroid	0.7 (20%)	8	138	7.6
(sol)	Total Body	50			
(insol)	GI(LLI)				
	Lung				
$^{137}_{55}Cs$ (β^-, γ)	Total Body	30 (100%)	1.1×10^4	70	70
(sol)	Liver	40			
	Spleen	50			
	Muscle	50			138
	Bone	100			138
	Kidney	100			
	Lung	300			
(insol)	Lung				
	GI(LLI)				
$^{210}_{84}Po$ (α)	Spleen	0.03 (8%)	138.4	60	46
(sol)	Kidney	0.04			
	Liver	0.1			
	Total Body	0.4			25
	Bone	0.5			
(insol)	Lung				
	GI(LLI)				

TABLE VII (CONT)

RADIONUCLIDE AND TYPE OF DECAY	ORGAN OF REFERENCE	MAXIMUM PERMISSIBLE BODY BURDENS (uci)	PHYSICAL HALF-LIFE ($t_{\frac{1}{2}}$ phy) (days)	BIOLOGICAL HALF-LIFE ($t_{\frac{1}{2}}$ bio) (days)	EFFECTIVE HALF-LIFE ($t_{\frac{1}{2}}$ eff) (days)
$^{226}_{86}$Ra(α, β^-, γ)	Bone	0.1	5.9×10^5	45	1.6×10^4
(sol)	Total Body	0.2			900
(insol)	GI(LLI)				
$^{233}_{92}$U (α, γ)	GI(LLI)		5.9×10^7		
(sol)	Bone	0.05			
	Kidney	0.08			300
	Total Body	0.4		120	100
(insol)	Lung				
	GI(LLI)				
$^{235}_{92}$U (α, β^-, γ)	GI(LLI)		2.6×10^{11}		
(sol)	Kidney	0.03			
	Bone	0.06			300
	Total Body	0.4		120	100
(insol)	Lung				
	(GI(LLI)				
$^{238}_{92}$U (α, β, e^-)	GI(LLI)		1.7×10^{12}		
(sol)	Kidney	5×10^{-3}			
	Bond	0.06			300
	Total Body	0.5		120	100
(insol)	Lung				
	(GI(LLI)				
$^{239}_{94}$Pu(α, γ)	Bone(99%)	0.04	8.9×10^6	7.3×10^4	
(sol)	Liver	0.4			
	Kidney	0.5			
	Total Body	0.4			6.4×10^4
(insol)	Lung				
	GI(LLI)				

*(%) indicates the percentage in critical organ of that in the total body.
** GI(LLI) indicates gastrointestinal tract, lower large intestine.

(2) Treatment.

Treatment for internal exposure should be under the supervision and direction of a physician. The radiological protection officer should supervise decontamination of the individual(s) concerned before leaving the work area and notify the physician of the type of material and suspected mode of entry into the body.

II. Student Performance Objectives of this Lesson.

A. Given a list of commonly used radiation sources and items containing radioactive isotopes, state the special hazards associated with each source/item, without error.

B. Given a list of commonly used radionuclides presenting special hazards, explain the methods of protecting radiation workers from the hazards presented, without error.

C. With references and a radionuclide presenting a special hazard, list the special procedures for decontamination as prescribed in TM 3-200.

III. Laboratory Exercise or Handouts: None.

IV. Problems and Solutions: None

V. References:

A. DA Pamphlet 39-3, The Effects of Nuclear Weapons, DA, Apr 62.

B. Medical Aspects of Radiation - a handbook for physicians, health physicists and industrial hygienists, Eugene L. Saenger, Editor, NRC, 1963.

C. TM 3-220, Chemical, Biological, Radiological (CBR) Decontamination, DA, Nov 67.

D. TB 750-237, Identification and Handling of Radioactive Items in the Army Supply System, DA, Feb 70.

E. Dangerous Properties of Industrial Materials, 2d Edition, N. Irvin Sax, 1963, Reinhold Publishing Corp.

F. Radiation Hazards and Protection, D. E. Barnes - Denis Taylor, 2d Edition, Pitman Publishing Corp, 1963, NY, London, Toronto.

G. Principles of Radiation Protection, G. Eaves, 1964, ILIFFE Books, Ltd., London.

H. Inorganic Chemistry, Therald Moeller, 1952, John Wiley and Sons, New York.

I. Plutonium - AEC Series, "Understanding the Atom," US Atomic Energy Commission, Oak Ridge, Tennessee, 37820. (Revised Edition - 1966).

DF080

RADIUM
HAZARDS AND CONTROL

DF080, RADIUM - HAZARDS AND CONTROL

I. References and Discussion.

A. References:

1. Report of Committee II, Permissible-Dose for Internal Radiation (1959).

2. Radium and Messothorium Poisoning and Dosimetry and Instrumentation in Technique Applied Radioactivity, MIT-952-1 (1964).

3. Diagnosis and Treatment of Radioactive, International AEA (1963).

B. Discussion:

RADIUM IN MAN

1. While the ex[illegible] [illegible]ds of radium were recognized almost immediately after its iso[illegible] [illegible]898, it was not until 1924 that the toxicity of internally dep[illegible] [illegible]um was realized.

Somewhere between 1914 and 1917, radium dial painting began in various locations throughout the world. One plant alone in New Jersey employed 800 girls between 1917 and 1925. These girls used to make a fine point on the brush, often by dipping the brush in the paint and drawing it between the lips. Then they would "point" rather than brush the radium on the dials. This necessitated repeated entry of the radium laden brush into the mouth, resulting in considerable ingestion of radium. Some of the girls even painted their lips, hair, and nails with the luminous material so that they would shine in the dark.

During the years 1922 to 1924, nine dial painting girls died with severe and unexplained anemia and destructive lesions of the jaw bone and mouth. In 1924 an article appeared in the Journal of the American Dental Association concerning the case of a girl who had osteomyelitis of the jaw. The author mentioned in a footnote that there was a possible causative connection between the girl's pathologic condition and radium dial painting. Almost simultaneously several other reports bearing on this possible relationship appeared in both the Journal of the American Dental Association and the Journal of the American Medical Association.

Both the lay public and factory officials became concerned as more and more cases of radium toxicity were reported. A complete and thorough investigation clearly established the causative agent to be radium. Protective steps were then taken (gloves, hoods, routine blood counts, etc.) in order to minimize further occupational exposure to this material. However, by this time, thousands of individuals throughout the world (mostly young girls) had been involved in radium dial painting, and the long-term effects of this exposure are still being observed today.

In addition to Radium-226, the luminous paint that was used on the east coast of the United States contained varying amounts of mesothorium (radium-228, half-life 6.7 years) and radiothorium (thorium-228, half-life 1.9 years). The art of making this paint belonged primarily to one individual, Dr. Fontesharke, who was very secretive about the ingredients and their amounts. Because of this, it is difficult to retrospectively estimate the initial body burdens (amount of radium in the body) of the dial painters, since most of the activity of radium-228 and all of the initial activity of thorium-228 has decayed. However, a body burden of some of the early dial painting cases of up to 200 microcuries has been postulated.

In 1931, 32 mental patients of the Elgin State Hospital, Elgin, Illinois received weekly intravenous injections of 10 microcuries of radium-226, up to a maximum of 45 weeks for the purpose of comprehensive measurement of radium retention. These individuals have been followed up to the present time, and have provided important information concerning radium retention in man.

Recently, a house occupied by a radium chemist and his family from about 1919 to 1950 was found to be contaminated with radium-226. The basement of the house was used as a radium laboratory. From 1950 to 1964 the house was sold twice, and a total of 22 residents of the house since 1919, 17 have been studied. It is of interest to note that after the house was sold in 1950, none of the adults or children have acquired a medically significant skeletal deposit radium, even though some of the individuals lived in this highly contaminated environment for as long as 10 years.

Up until 1932, the ingestion or injection of radium was an accepted medical practice. Additionally, patent medicines containing radium were sold to the public. As the harmful effects of internally deposited radium became better known, its medical use as a general panacea for illness ceased, until today it is used almost exclusively in sealed forms for its gamma radiation only. The early experience with internal radium deposition was not without value, for maximum permissible body burdens of radionuclides which localize in bone have been determined from a direct comparison with radium-226.

2. Absorption, Distribution and Excretion of Radium in the Body.

Early radium studies disclosed several basic facts:

a. Most of the radium which is taken up by the organism is excreted within a few days following administration and only a small portion remains for a very long time.

b. The excretion takes place mostly in the feces and only a small portion is excreted in the urine.

c. Because radium is chemically similar to calcium and is therefore metabolized in much the same way, the fraction of radium remaining in the organism is almost entirely deposited in bone.

d. Most of the radon, the first daughter product of radium, is exhaled through the lungs.

Although radium and calcium are handled similarly in the body, there exists a discrimination against radium and in favor of calcium in the absorption process. The degree of discrimination depends upon many factors, including solubility, particle size, and other material ingested with the radium, particularly the number of calcium ions available for competition. Estimates of the magnitude of discrimination against radium in the absorption process vary from 4 to 10 for man.

Following an intravenous injection of radium, the plasma concentration continually falls as a function of time. Since radium is incorporated in newly-formed bone mineral at the same concentration (radium to calcium) as it exists in the blood, mineral formed shortly after a dose of radium is administered will have a higher specific activity than mineral formed later. These localized high levels of activity have been termed "hot-spots."

The initial site of radium deposition occurs in what is known as an osteon, or localized area of bone which surrounds a nutrient canal. The bone cells lay down the calcium or radium in layers from the periphery inwards, in onion-like fashion; the oldest radium or calcium being deposited on the outermost layers. As the concentration of radium decreases in the blood, fewer radium atoms are available for incorporation in new osteons, and these then give the appearance of a diffuse distribution of radium throughout the bone.

Radium can also undergo true diffusion in bone, in two ways. The calcium (or radium) enters the osteon in a water phase during the early formation of bone mineral. At this stage of the formation of bone an exchange process can occur whereby radium can be replaced by calcium. Later, as water is replaced by mineral salts, further exchange of this kind ceases. However, later diffusion can occur through the action of osteoclasts, which resorb bone mineral, releasing radium and calcium ions into the bloodstream, where they once again become available for incorporation into newly forming osteons. By the process of exchange, then, radium from initial hot spots can become diffuse throughout bone. Experimental evidence has indicated that the diffuse radium activity is one-half of the total radium activity in bone.

Because the Elgin State Hospital patients received known doses of radium intravenously, it is possible to make several interesting calculations. For example, it was noted that weekly intravenous injections of 10 microcuries of radium gave an average terminal concentration of 14 picocuries per milligram of bone. Therefore the intravenous intake rate for any other measured terminal concentration can be estimated.

As indicated previously, the diffuse bone radium activity is dependent upon the total radium content in bone, with approximately half of the total radium activity found in a diffuse distribution. However, the maximum hotspot activity (pc/mg of bone) is dependent only upon the radium-to-calcium ratio in blood at the time of formation of the bone mineral. As the total length of the exposure increases the diffuse activity also increases, thereby causing a lower hotspot-to-diffuse ratio than a short exposure. For example, the hotspot-to-diffuse ratio for many radium dial painters (long exposure) was found to be approximately 40, while the hot-to-diffuse ratio of an Elgin State Hospital patient who received only 7 weekly injections was found to be 263.

Finally, if an ingestion discrimination factor of 4 to 10 is assumed, and if the ratio of hotspot-to-diffuse activity is 40, indicating chronic exposure, and if the hotspot was observed to have an activity of 42 pc/mg, we can retrospectively estimate that the individual ingested 120 to 300 microcuries per week of radium over a prolonged period of time.

Approximately 95 to 98 percent of radium excretion is by the feces, whereas 2 to 5 percent of the excretion is in the urine. The actual excretion of radium can be described by the power function $R_t = 0.54t^{-0.52}$, where R_t equals amount of radium retained after time t, and t equals time in days after injection.

Therefore, one day following injection the body retains about 60 percent of the total amount that is injected; after 1 week about 20 percent is retained; after 1 month about 9 percent is retained; and after 1 year about 2.5 percent is retained. At the end of 30 years, about 0.4 percent of the amount of radium is still retained.
It is estimated that once radium is incorporated into bone material, it has an effective half-life of 45-50 years.

3. Effects of Radium in the Body.

Acute doses of radium which fix large quantities (10-200 microcuries) in the skeleton lead to a short and fatal course, the manifestations of which may be leukopenia, secondary anemia, extensive hyperplasia of bone marrow, pathological changes in kidney and other soft tissue, necrosis of bone, loosening of teeth, chronic infection, weakness and death.

The long-term effects of lower doses are more subtle in appearance and may take years to become apparent. Assuming that 65 percent of the radium-226 daughter product, radon, is exhaled through the lungs, the total energy deposited in the skeleton per disintegration of radium-226 plus 35 percent of its daughter products is 11 MEV, mostly in the form of alpha particles, which have a high linear energy transfer. It has been determined that 0.1 microcurie of radium in bone will give a local dose of 0.6 rem/week. However, there are hotspots of from 30 to 260 times the activity of the diffuse distribution of radium. Because of this, body burdens of greater than 0.1 microcurie of radium can cause scarring and consequential decrease in the lumen of the vascular vessels of the bones, resulting in decrease of nutrients to those areas of the bone. When this occurs, the osteoclasts resorb the bone mineral, leaving a hollow area of necrosis. In the case of long bones, this will increase the incidence of fractures. One study has also indicated chromosome changes in the form of numerical as well as structural aberrations. In some patients, there was an increase beyond control values in the frequency of cells not having the normal chromosome number of 46, while structural aberrations consisted of chromosome fragments, deletions and translocations. This study included patients with body burdens of from less than 0.1 microcurie to 1.96 microcuries, although no significant number of cells with structural defects were observed in patients with body burdens of 0.1 microcurie or less.

Since ionizing radiation is a carcinogen, it is not suprising that a high incidence of osteogenic sarcoma has been found in patients with body burdens greater than 1.5 microcuries of radium-226, and the development of bone tumors many years after exposure has been the principal hazard to the dial painters and to patients given large medical doses of radium in unsealed forms.

4. Body Burden Determinations.

Since some of the radium daughters are gamma emitters, it is possible to assess the body burden by the use of a whole-body counter, employing sodium-iodide scintillation crystals.

A second method estimates body burden by correlation with radon exhaled as shown below. We know that 1 microcurie of radium-226 produces 2.22×10^6 atoms of Rn/min.

$$\text{Activity} = \lambda N$$

$$\text{Activity} = \frac{2.22 \times 10^6 \frac{\text{atoms of Rn}}{\text{minutes}} \times \frac{0.693}{3.825}\ \text{day} \times 1440 \frac{\text{minute}}{\text{day}}}{2.22\ \text{dpm/picocuries}}$$

$$= 126 \text{ picocuries of radon produced each minute}$$

Therefore, if there is a body burden of 1.0 microcurie, and 65 percent of radon produced is lost in the breath, then 82 picocuries of radon are exhaled in the breath each minute. If the average man exhales 7 liters/minute, then

$$\frac{82\ \text{picocuries/minute}}{7\ \text{liters/minute}} = 11.7 \text{ picocuries of radon/liters of breath,}$$

if the body burden is 1.0 microcuries of radium; or 1.17 picocuries of radon/liter of breath for each 0.1 microcurie of radium in the body.

5. Maxium Permissible Body Burden.

NBS Handbook #27, which was published in 1941, recommended that the maximum permissible body burden for radium-226 be established as 0.1 microcuries. This remains as an acceptable value to this day. The decision to use 0.1 microcuries was based on the observation that osteogenic sarcoma or other major clinical manifestations had not been found in subjects with body burdens of less than 1.5 microcuries of radium-226, and on the use of a factor of 10 as a margin of safety.

Although tumors have not been observed in persons with body burdens of radium as low as 0.1 microcurie, the factor of safety may not be as large as 10, since tumors have occurred in persons having a body burden of less than 1 microcurie at the time the tumor was first detected. In all these cases, however, the original body burden had been greater than this. Furthermore, in the case of the radium dial painters, the original dose was augmented by the addition of mesothorium (Ra-228) in the ingested material. At present-day occupational levels, it is estimated that the maximum permissible body burden would be reached only after 50 years of continuous exposure.

6. Inherent Disadvantages of Radium.

Radium-226, a naturally occurring radionuclide found as a daughter product in the uranium decay series, has a half-life of 1,622 years. As a member of the alkaline earth series, radium is chemically similar to calcium, strontium, and barium. Therefore, if it enters the body, it will probably be deposited in the bone where it may cause significant biological damage because of its long effective half-life and alpha decay. These properties make radium the most radiotoxic of the commonly used radionuclides.

Radium is a brilliant white metal that quickly turns black (nitride) in contact with the atmosphere. It behaves like the other alkaline metals, attacking glass or quartz and decomposing water to form an hydroxide. Therefore, the radium used in medicine and industry is combined in a more stable form as a chloride, bromide, or sulfate. Most of the radium processed in recent years is in the form of the insoluble sulfate. However, in 1933 Sayer reported that in a survey of radium sources in medical institutions, 18 percent of the radium was in the form of a chloride, 26 percent in a bromide form, and 54 percent was in a sulfate form. The remaining 2 percent was radium carbonate or some other compound. These salts are hermetically sealed in tubes, needles, cells, or capsules where they can be manipulated to produce the desired exposure. Since these salts are in the form of a fine powder, rupture of the sealed container will result in the dispersal of the radium, making recovery and decontamination operations difficult. Because radium-226 has a 1,622-year half-life, decontamination is necessary rather than restricting the area until the activity has decayed to acceptable levels, as can be done in similar incidents with some of the short-lived radionuclides.

It should also be pointed out that the dosage calculations in radiation therapy are based on the assumption that the radium is uniformly distributed throughout the active length of the source. Barium salts are usually added to the radium salts to fill the container completely. However, Freed and co-authors have observed by autoradiography of radium needles that these salts may become unevenly packed, resulting in a considerable discrepancy in the expected tissue dose as calculated from a uniformly packed needle. They recommend a periodic inspection and autoradiograph of sources used in therapy.

Another characteristic of radium is its complex series decay. Radium-226 is primarily an alpha emitter, as are its daughters, radon-222, polonium-218, and polonium-214. The gamma activity that makes radium applicable in medicine and industry comes from the beta-gamma decay of two other daughters, lead-214 and bismuth-214. To be an effective gamma emitter, a radium source must be sealed for approximately 30 days to allow its daughter products to reach equilibrium with the radium. Unfortunately, internal pressure builds up inside the sealed source. This pressure is partly caused by the radon gas (3.28×10^{-3} atmospheres per year for a 1 mg source), the helium buildup from the alpha decay (1.09 atmospheres per year for a 1 mg source), but primarily by the generation of hydrogen and oxygen in the dissociation of any water present as a result of inadequate drying of the salts before they are sealed in the source. The pressure from this dissociation has been estimated to reach several hundred atmospheres. Extreme care must be exercised in handling sealed radium sources, for there is no way of determining when a source may have reached the point of failure. Rough handling and heat sterilization should be avoided as they may add sufficient external stress to initiate rupture or leakage. Older sources encapsulated in glass or fitted with a friction plug without threads are particularly susceptible to failure from internal pressure.

Leaking sources are not only a potentially severe health hazard because of the spread of finely divided radium salt if the hermetic seal fails completely, but, in addition, the sources will not deliver the expected gamma dose because the radon daughter products are not in equilibrium with radium.

The decrease in the cost of radium over the years has also contributed to unnecessary exposures. Many users who purchased radium when the price was inflated are reluctant to part with the sources at the present low price. Therefore, some owners who no longer have a use for radium have retained it as a kind of radioactive "white elephant." Sources have been stored in such unlikely places as safe deposit boxes.

The characteristics of radium just described merely suggest its potential hazards. In order to evaluate public health aspects, it is necessary to know the frequency and extent of the uses of radium.

7. Calibration of a Leak Test Procedure for Sealed Radium Sources.

a. Object.

To correlate survey instrument readings with the amount of radium plus daughter's leakage.

b. Introduction.

There are many leak test procedures for sealed radium sources in use today. The majority of these test methods collect the daughter products of radon for several hours and this activity is monitored with a suitable instrument. The test procedure determined the instrument that should be used in measuring the amount of radon daughters collected. In some of the leak tests, the alpha activity is determined with an instrument such as the AN/PDR-60 (PAC 1SA). Precise measurements of the leakage can be obtained by the use of an elaborate laboratory instrument for detecting radon, but field use of this instrumentation is not practical.

c. List of Equipment.

6 calibrated radium sources with activity of 0.001 uc - 0.15 uc.

6 jars for conducting the test.

1 alpha survey meter.

d. Procedure.

(1) Day 1 - The first step is to prepare the radium sources to be used. A stock solution with a concentration of 2 u gram/ml is used for the sample preparation. The solution is calibrated and the volume needed for each sample determined. A micropipette is then used to remove the liquid from the container and place it on a 2-inch planchet. The sample is then dried and standardized in an internal proportional counting instrument.

(2) The radium sources are then placed in the test jar for 24 hours.

(3) Day 2 - The activity on each jar lid is measured with the alpha survey meter at the end of the 24-hour test period. A reading is also made of the alpha check source, if one is available. This will allow one to check the operation of the instrument prior to each survey. If there is a significant change in the reading of the standard source, a correction factor may be obtained by dividing the initial reading by the present reading. This factor must then be multiplied by the readings taken during the survey. A new calibration should be made as soon as possible because this correction factor is based only on one point.

(4) The next step is to plot a calibration curve of activity versus counts per minute on linear paper. This curve will provide an estimate of the radium plus daughter's leakage when a reading is obtained with the survey instrument.

DATA SHEET

Source Number	Calibrated Activity	Time of Test	Reading obtained
1			
2			
3			
4			
5			
6			

Type of Alpha survey instrument ____________________.

Reading on check source ____________________.

Date ____________________.

Calibration made by ____________________.

Location ____________________.

II. Student Performance Objectives and Notes:

A. Student Performance Objectives.

1. State radium usage of concern to the radiological safety officer and the problems encountered in this usage.

2. Give the characteristics and hazards associated with radium usage to include accident control.

3. State the reasons for detecting radium and give types of leakage test which can be performed to detect radium.

4. Give the precautions necessary to preclude or reduce the significance of radium accidents.

B. Notes:

III. Handouts.

Vu-Graphs used in DF080:

A. ^{60}Co Advantages.

1. No gaseous radioactive daughters.
2. Metallic form.
3. Machined to one desired shape.
4. Less radiotoxic.
5. Does not build up an internal pressure in sealed sources.

B. Problems Encountered with Radium.

1. Storage
2. Shielding
3. Identification and Labeling
4. Leak Testing Procedures
5. Records and Logs
6. Radiation Protection

C. Accident Study I - Percent Occurrence

94 Medical Cases

1. Transfer from storage and assembly - 5%
2. Transfer to treatment room and application - 3%
3. Patient irradiation - 26%
4. Removal and transfer to storage - 55%
5. Disassembly and transfer to storage - 11%

D. Accident Study 2, Percent Occurrence.

1. Truck - 80 cases - 54%

2. Sewerage System - 19 cases - 13%

3. Floor - 15 cases - 10%

4. Other - 33 cases - 23%

E. Reasons for Detecting Radium

1. If all radon gas escapes - no gamma

2. Cross - contamination

3. Interference with instrumentation

4. Leak may not get worst - but will not get better

F. Types of Leakage

1. Diffusion

2. Expulsion of radon

3. Expulsion of radon daughters

4. Expulsion of radium

G. Other Test for Radium

1. Wipe test or smear test

2. Alpha instrument survey

3. Well insert

4. Radon film badge

5. Closed system - radon plus daughter retention

6. Closed system - radon daughters only

7. Glass jar

H. Radium Decay I.

GROUP I

$$^{226}Ra \xrightarrow[1602\ yrs]{\alpha,\ \gamma}$$

GROUP II

$$^{222}Rn \xrightarrow[3.823\ da]{\alpha}$$

GROUP III

$$^{218}Po^{RaA} \xrightarrow[3.05]{\alpha} \quad ^{214}Pb^{RaB} \xrightarrow[26.8\ m]{\beta^-,\ \alpha} \quad ^{214}Bi^{RaC} \xrightarrow[19.7\ m]{\beta\ \ \gamma} \quad ^{214}Po^{RaC} \xrightarrow[1.64 \times 10^{-4} s]{\alpha}$$

GROUP IV

$$^{210}Pb^{RaD} \xrightarrow[21\ yrs]{\beta^-,\ \gamma} \quad ^{210}Bi^{RaE} \xrightarrow[5.01\ d]{\beta^-} \quad ^{210}Po^{RaF} \xrightarrow[138.4\ d]{\alpha} \quad ^{206}Pb^{RaG}$$

I. Radium Considerations.

GROUP I - Radium - effective half-life - 1602 years

GROUP II - Radon - effective half-life - 3.823 days

GROUP III - Primary daughters of radon - effective half-life - 26.8 months.

GROUP IV - Secondary daughters of radon - effective half life - 21 years.

J. Precautions.

1. Accountability
2. Custodian
3. Adequate storage
4. Rigid control
5. Proper transportation
6. Proper security

K. Preplanning for Accidents.

1. Where isotope is used

2. How isotope is used

3. Capability of isolating contaminated area

4. Monitoring equipment capability

5. Cleaning equipment available

6. What help is available

7. Training

IV. Problems: None

V. Solutions: None

SHIELDING OF X AND GAMMA RADIATION

DF100, SHIELDING OF X AND GAMMA RADIATION

I. Reference: ST 3-155, paragraph 4.3, 4.6, 4.9, table 4.1; U. S. Army Ordnance Center and School Pam 25 (bring to class).

II. Student Performance Objectives.

A. Review nature and origin of X-ray and gamma radiation.

B. Explain production of X-ray and gamma radiation to include bremsstrahlung and the energy ratio between X-ray and gamma radiation.

C. Explain, from memory and in general terms, electromagnetic energy absorption to include the photoelectric effect, Compton effect, and pair production.

D. Define the factors influencing absorption efficiency.

E. Define and explain linear attenuation coefficients.

F. Define and explain mass attenuation coefficients.

G. Define half-thickness concept and its relation to the basic shielding equation.

H. Given Pam 25 as a reference, the radioactive material to be used, and the type of shielding material, determine half-thickness.

Notes:

III. Handouts: None

IV. Problems - Shielding of X and Gamma Radiation:

Class and Home Study Problems.

1. Complete the following table:

	GAMMA ENERGY (Mev)	SHIELD	μ/ρ (cm^2/gm)
a.	3.6	Lead	
b.	0.032	Sandstone (SiO_2)	
c.	0.640	Tin	

2. Complete the following table:

	GAMMA ENERGY (Mev)	SHIELD	μ/ρ (cm^2/gm)	μ (cm^{-1})
a.	1.48	Iron		
b.	1.13	Copper		
c.	0.855	Aluminum		

3. A certain X-ray machine produces energy so that the total mass attenuation coefficient is 0.225 cm^2/gm in copper.

a. What is the linear attenuation coefficient?

b. What is the half-thickness of the copper to this X-ray?

4. a. What is the half-thickness of uranium for gamma radiation of 1.49 Mev?

b. What is the half-thickness of lead for gamma radiation of 1.22 Mev?

c. What is the half-thickness of concrete for X-ray radiation of 0.038 Mev (for density use worst case involving siliceous concrete)?

5. Find the half-thickness values for carbon and air when subjected to the gamma radiation for each of the following isotopes. (Density of air 0.0013 gm/cm^3, and density of carbon 2.25 gm/cm^3.)

	E	Carbon			Air		
		μ/ρ	μ	$X_{\frac{1}{2}}$	μ/ρ	μ	$X_{\frac{1}{2}}$
a. ^{48}V							
b. ^{51}Cr							
c. ^{63}Ni							
d. ^{91}Sr							
e. ^{131}I							

6. What is the half-thickness of copper for gamma radiation from ^{113}Sn?

7. a. What is the half-thickness of aluminum for the gamma radiation from ^{125}I?

b. What would be the half-thickness of copper in part a?

8. The basic shielding equation is $R = R_o e^{-\mu x}$. If a thickness of 12 cm is used and μx is equal to 7.2, what is the value of μ?

V. Solutions to Problems.

1.

	GAMMA ENERGY (Mev)	SHIELD	μ/ρ (cm^2/gm)
a.	3.6	Lead	0.0417
b.	0.032	Sandstone (SiO_2)	0.780
c.	0.640	Tin	0.0787

2.

	GAMMA ENERGY (Mev)	SHIELD	μ/ρ (cm^2/gm)	μ (cm^{-1})
a.	1.48	Iron	0.0493	0.387
b.	1.13	Copper	0.0561	0.502
c.	0.855	Aluminum	0.0665	0.179

3. a. Linear attenuation coefficient - 2.012.

$$\mu/\rho \times \rho = \mu$$

$$0.225 \times 8.92 = 2.01150$$

b. The half-thickness of the copper is 0.344 cm.

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{2.012} = 0.344 \text{ cm}$$

4. a. (1) E = 1.49

(2) μ/ρ for uranium (page 138, Pam 25)

$$\begin{array}{rl} 1 \text{ Mev} & = 0.0776 \\ 1.5 \text{ Mev} & = \underline{0.0548} \\ & \ 0.0228 \times \dfrac{49}{50} = 0.0223 \end{array}$$

$$\begin{array}{r} 0.0776 \\ \underline{0.0223} \\ 0.0553 \end{array} = \mu/\rho \text{ for } 1.49 \text{ Mev}$$

(3) ρ for uranium = 18.68 gm/cm^3.

(4) $\mu = \mu/\rho \times \rho$

$\mu = 0.0553 \times 18.68$

$\mu = 1.033$

(5) $X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{1.033} = 0.671$ cm

b. (1) E = 1.22

(2) μ/ρ for uranium (page 138)

$$\begin{array}{lll} 1 \text{ Mev} & = 0.0708 & \\ \underline{1.5} \text{ Mev} & = \underline{0.0517} & \\ .5 & 0.0191 \times \frac{11}{25} & = 0.0084 \end{array}$$

$$\begin{array}{r} 1.22 \\ -\underline{1.00} \\ 0.22 \end{array} \qquad \frac{0.22}{0.50} = \frac{11}{25}$$

$$\begin{array}{r} 0.0708 \\ -\underline{0.0084} \end{array}$$

$0.0624 = \mu/\rho$ for 1.22 Mev absorbed in Pb.

(3) ρ for lead = 11.35

(4) $\mu = \mu/\rho \times \rho$

$\mu = 0.0624 \times 11.35 = 0.708$

(5) $X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{0.708}$

$X_{\frac{1}{2}} = 0.979$ cm

c. (1) E = 38 Kev.

(2) μ/ρ for concrete. 30 Kev = 1.190
40 Kev = $\underline{0.605}$

$$\begin{array}{l} 38 \text{ Kev} \\ \underline{30 \text{ Kev}} \\ 8 \end{array} \quad \frac{8}{10} = \frac{4}{5} \qquad 0.585 \times \frac{4}{5} = \underline{0.468}$$

$$\begin{array}{r} 1.190 \\ \underline{0.468} \\ 0.722 \end{array} = \mu/\rho \text{ for concrete at 38 Kev.}$$

(3) ρ for concrete 2.25 gm/cm^3

(4) $\mu = \mu/\rho \times \rho$

$\mu = 0.722 \times 2.25$

$\mu = 1.625 \text{ cm}^{-1}$

(5) $X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{1.625} = 0.426 \text{ cm}$

5.

		E	Carbon			Air		
			μ/ρ	μ	$X_{\frac{1}{2}}$	μ/ρ	μ	$X_{\frac{1}{2}}$
a.	^{48}V	2.241 (3%)	0.0424	0.0954	7.27 cm	0.0415	0.000054	1.28×10^4
b.	^{51}Cr	0.320 (9%)	0.1047	0.236	2.94 cm	0.1047	0.000136	5.1×10^3
c.	^{63}Ni	No γ	-	-	-	-	-	-
d.	^{90}Sr	No γ	-	-	-	-	-	-
e.	^{131}I	0.637 (6.8%)	0.0789	0.178	3.89 cm	.0787	0.000102	6.79×10^3

6. a. E of ^{113}Sn = 0.255

b. μ/ρ = 200 = .157   .157
    300 = .112   -.025
    100    $.045 \times \frac{11}{20}$ = .025   .132

$\mu/\rho = 0.132$

c. $\rho = 8.94 \text{ gm/cm}^3$

d. $\mu = \mu/\rho \times \rho$

$\mu = 0.132 \times 8.94$

$\mu = 1.18$

$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{1.18}$

$X_{\frac{1}{2}} = .587$ cm

7. a. (1) E = 0.035

(2) μ/ρ

$$\begin{array}{lll} 30 \text{ Kev} = 1.120 & & 1.120 \\ 40 \text{ Kev} = \underline{0.567} & & \underline{0.277} \\ \underline{10} \quad\quad 0.553 \times \frac{1}{2} & = 0.277 & 0.843 \end{array}$$

$\mu/\rho = 0.843$

(3) $\rho = 2.699$ or 2.7 gm/cm^3

(4) $\mu = \mu/\rho \times \rho = 2.28$

(5) $X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{2.28}$

$X_{\frac{1}{2}} = 0.304$ cm

b. (1) E = 0.035

(2) μ/ρ

$$\begin{array}{lll} 30 \text{ Kev} = 10.90 & & 10.90 \\ 40 \text{ Kev} = \underline{4.89} & & \underline{3.005} \\ \underline{10} \quad\quad 6.01 \times \frac{1}{2} & = 3.005 & 7.895 \end{array}$$

$\mu/\rho = 7.895$

(3) $\rho = 8.94 \text{ gm/cm}^3$

(4) $\mu = \mu/\rho \times \rho = 7.895$

$\mu = 70.58$

(5) $X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{70.58}$

$X_{\frac{1}{2}} = 0.00981$ cm

8. $\mu x = 7.2$

$x = 12 \text{ cm}$

$\therefore \mu (12 \text{ cm}) = 7.2$

$\mu = \frac{7.2}{12 \text{ cm}} = 0.6 \text{ cm}^{-1}$

$\mu = 0.6 \text{ cm}^{-1}$

BASICS OF RADIATION DETECTION

DF110

DF110, BASICS OF RADIATION DETECTION

I. Reference: ST 3-155, paragraph 3.4, 4.1-4.3, 4.5-4.8, ch 6.

II. Lesson Objectives and Notes:

A. Five principles of radiation detection.

B. Application of these principles to Radiac instruments.

COMPUTATIONAL PROCEDURES IN PHYSICAL SCIENCES

Notes:

III. Handouts: DF110 Nomenclature Interpretation.

IV. Problems: None.

V. Solutions: None.

RADIACMETER NOMENCLATURE INTERPRETATION

1.	Letters before	AN	Army Navy Set
2.	First Letter after	M	Mobile
		P	Portable or Pack
		T	Ground Transportable
		U	General Utility (Airborne, Shipboard, Ground)
3.	Second Letter after	D	Radiac
		F	Photographic
4.	Third Letter after	H	Recording
		M	Maintenance and Testing
5.	Letter after	T	Training
6.	Number after		Model number
7.	Letter after number		Modification (First, Second, etc)

COMPONENT INDICATORS

1.	Letter	CY	Cases
		IM	Intensity Measuring Device
		MX	Miscellaneous
		PP	Power Supply
		TS	Test Equipment

DF130, COMPUTATIONAL PROCEDURES IN PHYSICAL SCIENCES

I. Reference: None

II. Lesson Plan Outline: None

III. Handouts: None

IV. Problems: Class and Home Study Problems

1. For the following elements, how many protons and neutrons are present?

a. $^{60}_{27}Co$

Protons ______________

Neutrons ______________

b. $^{238}_{92}U$

Protons ______________

Neutrons ______________

c. $^{208}_{82}Pb$

Protons ______________

Neutrons ______________

2. For elements listed in problem 1, how many electrons must be present for the atom to be electrically neutral?

a. ______________

b. ______________

c. ______________

3. Calculate the (Q) value for the following reaction:

$$^{14}_{7}N + ^{4}_{2}\alpha \rightarrow ^{1}_{0}n + ^{17}_{9}F + Q$$

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4. For shielding purposes what gamma energy should be considered for

a. $^{71}_{33}As$?

b. $^{130}_{53}I$?

c. $^{129}_{52}Te$?

d. $^{111}_{47}Ag$?

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5. If 180 ergs of energy were absorbed in 9 gms of tissue, what amount of radiation was present to cause this damage?

6. What is the mass attenuation coefficient of a

a. .1 Mev γ in copper?

b. 2 Mev γ in iron?

c. 1.5 Mev γ in aluminum?

7. What are the linear attenuation coefficients for each of the conditions in problem 6?

8. What is the half-thickness of each of the materials listed in problem 6?

9. If a sample of radioactive material decays at a rate of 7.2×10^{10} disintegrations per second, how many curies does this represent? How many microcuries?

10. If doses of the following radiations are received, what is the total biological damage?

3 rad of beta
4 roentgen of gamma
0.5 rad of fast neutron
0.25 rad of slow neutron

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11. What are the half-lives of the following?

a. $^{54}_{27}Co$

b. $^{119}_{51}Sb$

c. $^{245}_{94}Pu$

d. $^{181}_{74}W$

12. What is the penetration of a 5 Mev beta particle in silver?

13. A man works 5 meters from a radioactive source which has a source strength of 2.5 rhm, for 45 minutes. What dose should he receive?

14. A radioactive sample of ^{67}Cu, having a dose rate of 980 mrad/hr at 1 meter, has just arrived. When will the dose rate of this sample be down to 320 mrad/hr at 1 meter?

15. a. What are the daughter products when the following nuclides decay?

(1) $^{68}_{29}Cu$

(2) $^{18}_{9}F$

(3) $^{221}_{89}Ac$

(4) $^{165}_{68}Er$

b. Balance the following reactions.

(1) Li (d,n) $^{7}_{4}Be$

(2) ^{33}S (n, ?) ^{33}P

(3) ^{62}Ni (?,γ) ^{63}Ni

(4) ? (n,α) $^{78}_{33}As$

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16. If 6 esu of charge was generated by radiation in a volume of 24 cc of air, what exposure dose of radiation was present?

17. You as Radiological Safety Officer have been asked to check a package to ship 1 Ci of $^{184}_{75}Re$ which has a source strength of 0.509 rhm. To ship this package, the reading at the surface must not exceed 200 mrad/hr and at one meter from surface must not exceed 10 mrad/hr. How much lead would be required to ship this package if the package is 1 meter to a side?

18. a. What thickness of beryllium would be required to stop the beta particles from a 59.8 rhm source of ^{95}Zr in equilibrium with its daughter product ^{95}Nb?

b. What is the unshielded dose rate 30 cm from the source?

19. a. It takes a medical technologist 3 minutes to prepare a 1.5 rhm radioisotope for injection in a patient. During the preparation time the technologist is 1 meter from the source with no shielding. What dose does he receive?

b. The technologist also must take the prepared injection to the patient's room. It takes him 5 minutes to transport the injection during which time the source is 2 meters away from him. What dose does he receive during this operation?

20. a. The radioactivity of a nuclide decreased by 40% in 45 minutes. What is this nuclide's half-life?

b. How long will it take for 75% of the activity to be dissipated?

V. Solutions.

1. In the A-Z notation "$^{A}_{Z}X$", Z = number of protons, and number of neutrons = A-Z.

a. $^{60}_{27}Co$

Protons: 27

Neutrons: 60 - 27 = 33

b. $^{238}_{92}U$

Protons: 92

Neutrons: 238 - 92 = 146

c. $^{208}_{82}Pb$

Protons: 82

Neutrons: 208 - 82 = 126

2. For an atom to be electrically neutral, it must have as many electrons as protons; therefore,

a. 27

b. 92

c. 82

3. $^{14}_{7}N + ^{4}_{2}\alpha \rightarrow ^{1}_{0}n + ^{17}_{9}F + Q$

Obtain mass from page 51, Pam 25.

$^{14}_{7}N$ - 14.003074 amu $\qquad$ $^{1}_{0}n$ - 1.008665 amu

* $^{4}_{2}He$ - $\underline{4.002603 \text{ amu}}$ $\qquad$ $^{17}_{9}F$ - $\underline{17.002096 \text{ amu}}$

18.005677 amu $\qquad$ 18.010761 amu

*NOTE: The mass of $^{4}_{2}He$ is used rather than the mass of $^{4}_{2}\alpha$ to make the electron masses balance across the equation.

Determine Mass Defect.

$$\begin{array}{r} 18.010761 \\ \underline{-18.005677} \\ 0.005084 \text{ amu} \end{array}$$

0.005084 amu x 931.48 Mev/amu = 4.735644 Mev. Since the mass of the product is greater than the mass of the reactants the reaction required energy to be added to make the reaction proceed. As the original equation was written this energy term is then negative.

4. a. ^{71}As has the following gammas (page 256, Pam 25):

E_1 = 0.511 Mev

E_2 = 0.175 Mev

Use the most energetic gamma or 0.511 Mev.

b. ^{130}I has the following gammas (page 298, Pam 25):

E_1 = 0.419 Mev

E_2 = 0.538 Mev

E_3 = 0.669 Mev

E_4 = 0.743 Mev

E_5 = 1.15 Mev

Use the most energetic gamma or 1.15 Mev.

c. ^{129}Te has the following gammas (page 296, Pam 25):

E_1 = 1.08 Mev (1.5%)

E_2 = 0.81 Mev (0.5%)

E_3 = 0.455 Mev (15%)

E_4 = 0.027 Mev (19%)

E_5 = 0.275 Mev (1.7%)

Use the most energetic gamma which occurs 3% or greater - 0.455 Mev.

d. ^{111}Ag has the following gammas (page 282, Pam 25):

E_1 = 0.342 Mev

E_2 = 0.247 Mev

Use the most energetic gamma or 0.342 Mev.

5. $1 \text{ rad} = \frac{100 \text{ ergs}}{\text{gm}}$

$\frac{180 \text{ ergs}}{9 \text{ grams}} = \frac{20 \text{ ergs}}{\text{gm}}$

$\frac{20 \text{ ergs/gm}}{100 \text{ ergs/gm/rad}} = \underline{0.2 \text{ rad}}$

6. a. $\frac{\mu}{\rho} = 0.0589 \text{ cm}^2/\text{gm}$ (page 138, Pam 25)

b. $\frac{\mu}{\rho} = 0.0425 \text{ cm}^2/\text{gm}$ (page 138, Pam 25)

c. $\frac{\mu}{\rho} = 0.050 \text{ cm}^2/\text{gm}$ (page 137, Pam 25)

7. a. $\rho = 8.94 \text{ gm/cm}^3$ for copper (page 65, Pam 25)

$\mu = \frac{\mu}{\rho} \times \rho = (0.0589)(8.94) = \underline{\underline{0.527 \text{ cm}^{-1}}}$

b. $\rho = 7.86 \text{ gm/cm}^3$ for iron (page 65, Pam 25)

$\mu = \frac{\mu}{\rho} \times \rho = (0.0425)(7.86) = \underline{\underline{0.334 \text{ cm}^{-1}}}$

c. $\rho = 2.699 \text{ gm/cm}^3$ for aluminum (page 65, Pam 25)

$\mu = \frac{\mu}{\rho} \times \rho = (0.050)(2.699) = \underline{\underline{0.1350 \text{ cm}^{-1}}}$

8. $X_{1/2} = \frac{0.693}{\mu}$

a. $X_{1/2} = \frac{0.693}{0.527} = \underline{\underline{1.31 \text{ cm for copper}}}$

b. $X_{1/2} = \frac{0.693}{0.334} = \underline{\underline{2.07 \text{ cm for iron}}}$

c. $X_{1/2} = \frac{0.693}{0.1350} = \underline{\underline{5.13 \text{ cm for aluminum}}}$

9. a. 1 curie = 3.7×10^{10} dis/sec

$\frac{7.2 \times 10^{10}}{3.7 \times 10^{10}} = \underline{\underline{1.95 \text{ curies}}}$

b. 1 curie = 10^6 µCi

$\underline{\underline{1.95 \times 10^6 \text{ µCi}}}$

10. 3 rad of beta x RBE of 1 = 3 rem

4 r of gamma x RBE of 1 = 4 rem

0.4 rad of fast neutron x RBE of 10 = 5 rem

0.25 rad of slow neutron x RBE of 5 = 1.25 rem

TOTAL DOSE = 13.25 rem

11. a. 0.194 sec (page 249, Pam 25)

b. 38.0 hours (page 291, Pam 25)

c. 10.1 hours (page 373, Pam 25)

d. 140 days (page 336, Pam 25)

12. R = 2550 mg/cm^2 (page 123, Pam 25)

ρ = 10.50 gm/cm^3 (page 65, Pam 25)

$X = \frac{R}{\rho} = \frac{2550 \text{ mg/cm}^2}{10{,}500 \text{ mg/cm}^3} = \underline{\underline{0.243 \text{ cm}}}$

13. $$R = \frac{S}{d^2}$$

$$R = \frac{2.5}{(5)^2} = 0.1 \text{ rad/hr}.$$

$$D = RT$$

$$D = 0.1 \frac{\text{rad}}{\text{hr}} \times 45 \text{ min} \times \frac{1 \text{ hour}}{60 \text{ min}}$$

$$D = 0.075 \text{ rad or } \underline{\underline{75 \text{ mrad}}}$$

14. $$R_o = 980 \text{ mrad/hr}$$

$$R = 320 \text{ mrad/hr}$$

$$t_{\frac{1}{2}} = 58.5 \text{ hrs (page 252, Pam 25)}$$

$$t = ?$$

$$R = \frac{R_o}{2^n}$$

$$2^n = \frac{R_o}{R} = \frac{980}{320} = 3.06$$

$$n = 1.7 \ (2^n \text{ Table})$$

$$n = \frac{t}{t_{\frac{1}{2}}}$$

$$t = nt_{\frac{1}{2}}$$

$$t = (1.7)(58.5)$$

$$t = \underline{\underline{99.5 \text{ hours}}} \approx 4 \text{ days, } 3\tfrac{1}{2} \text{ hours}$$

15. a. (1) $^{68}_{29}Cu \rightarrow {}^{0}_{-1}e + {}^{68}_{30}Zn + Q$ (Decays by β^-, p 252, Pam 25)

or from page ~~74~~, Pam 25, you can read directly $^{68}_{30}Zn$.

(2) $^{18}_{9}F$ decays by β^+ 97% of the time and EC 3% of the time (page 235, Pam 25)

$$^{18}_{9}F \rightarrow {}^{0}_{+1}e + {}^{18}_{8}O + Q$$

$$^{18}_{9}F + {}^{0}_{-1}e \rightarrow {}^{18}_{8}O + Q.$$

Or from page 72, Pam 25, you can read directly $^{18}_{8}O$.

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(3) $^{221}_{89}Ac$ decays by α (page 365, Pam 25)

$$^{221}_{89}Ac \rightarrow {}^{4}_{2}He + {}^{217}_{87}Fr + Q$$

Or from page 83, Pam 25, you can read directly $^{217}_{87}Fr$.

(4) $^{165}_{68}Er$ decays by EC ~~(page 326, Pam 25)~~

$$^{165}_{68}Er + {}^{0}_{-1}e \rightarrow {}^{165}_{67}Ho + Q$$

Or from page 81, Pam 25, you can read directly $^{165}_{67}Ho$.

b. (1) $^{6}_{3}Li + {}^{2}_{1}d \rightarrow {}^{1}_{0}n + {}^{7}_{4}Be + Q$

(2) $^{33}_{16}S + {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{33}_{15}P + Q$

(3) $^{62}_{28}Ni + {}^{1}_{0}n \rightarrow {}^{0}_{0}\gamma + {}^{63}_{28}Ni + Q$

(4) $^{81}_{35}Br + {}^{1}_{0}n \rightarrow {}^{4}_{2}He + {}^{78}_{33}As + Q$

16. 1 r = 1 esu/cc of air

$$\frac{6 \text{ esu}}{24 \text{ cc}} = \frac{0.25 \text{ esu}}{\text{cc}}\left|\frac{1 \text{r.}}{1 \text{ esu/cc}}\right. = \underline{\underline{0.25 \text{ r}}}$$

17. GIVEN: S = 0.509 rhm

FIND R at surface

$d = .5$ meters

$R_o = \frac{S}{d^2}$

$R_o = \frac{0.509}{(.5)^2}$

R_o = 2.036 rad/hr at surface

R_o = 2036 mrad/hr

R = 200 mrad/hr

μ/ρ for .905 Mev gamma in lead $= 0.0797 \text{ cm}^2/\text{gm}$

$\mu = \mu/\rho \times \rho = 0.0797 \times 11.35 = 0.905 \text{ cm}^{-1}$

$X_{\frac{1}{2}} = \frac{0.693}{\mu}$

$n = \frac{X}{X_{\frac{1}{2}}}$

18. a. Beta energies and %'s for ^{95}Zr: (page 393, Pam 25)

0.89 Mev (2%)

0.396 Mev (49%)

0.360 Mev (49%)

Beta energies for ^{95}Nb (page 393, Pam 25)

0.1597 (~100%)

Beta energy (max) = 0.396 Mev

$R = 113\ mg/cm^2$

$\rho = 1.80\ gm/cm^3 \times 1000\ mgm/gm = 1800\ mg/cm^3$

$$X = \frac{R}{\rho} = \frac{113}{1800} = \underline{6.28 \times 10^{-2}\ cm}$$

b. Source strength:

GIVEN: S = 59.8 rhm

$$R_o = \frac{S}{d^2} = \frac{59.8}{(0.3)^2} = \underline{\underline{665\ rad/hr}}$$

19. a. $R_o = \dfrac{S}{d^2}$

$$R_o = \frac{1.5\ rhm}{(1)^2} = 1.5\ rad/hr$$

$$D = R \times T$$

$$D = 1.5\ rad/hr \times \frac{3}{60}$$

$$D = \frac{4.5}{60} = 0.075\ rad$$

$$D = \underline{\underline{75\ mrad}}$$

b. $R_o = S/d^2$

$$R_o = \frac{1.5 \text{ rhm}}{(2)^2} = \frac{1.5}{4} = 0.375 \text{ rad/hr}$$

$$D = R \times T$$

$$D = 0.375 \text{ rad/hr} \times \frac{5}{60}$$

$$D = 0.03125 \text{ rad}$$

$$D = \underline{\underline{31.25 \text{ mrad}}}$$

20. a. $R_o = R_o$

$$R = R_o - 0.4\, R_o = 0.6\, R_o$$

$$t = 45 \text{ min}$$

$$t_{\frac{1}{2}} = ?$$

$$2^n = \frac{R_o}{R} = \frac{R_o}{0.6\, R_o} = \frac{1}{0.6} = 1.667$$

$$n = 0.7$$

$$t_{\frac{1}{2}} = \frac{t}{n} = \frac{45 \text{ min}}{0.7} = \underline{\underline{64.3 \text{ minutes}}}$$

b. $R_o = R_o$

$$R = R_o - 0.75\, R_o = 0.25\, R_o$$

$$t = ?$$

$$t_{\frac{1}{2}} = 64.3 \text{ min}$$

$$2^n = \frac{R_o}{R} = \frac{R_o}{0.25\, R_o} = \frac{1}{0.25} = 4$$

$$n = 2$$

$$t = nt_{\frac{1}{2}} = (2)(64.3 \text{ min}) = \underline{\underline{128.6 \text{ minutes}}}$$

DF140

RADI-AC INSTRUMENTS

I. Lesson Objectives and Notes:

A. Discussion of purpose of radiation dosimetry, types of dosimeters, theory, maintenance and calculations for ion chamber dosimeters.

B. Charging procedures for ion chamber dosimeters.

C. Theory, operation, functioning and employment of ion chamber, area radiological survey meters.

D. The operation, use and maintenance of the AN/PDR-27(J) Radiac Set.

1. Film badge dosimeter

   a. Principle of detection

   b. Composition

   c. Film badge service

2. Standard Ionization Chamber Dosimeters

   a. Principle of operation

   b. General characteristics

	IM93( )/UD	IM147/PD	IM9( )/PD
Range			
Use			
Basis of issue	2/Platoon	1/Individual	1/Individual
Leakage rate	12 Rad/24 hr	1 Rad/24 hr	4 Mrad/24 hr
Accuracy	±10%	±10%	±10%
Radiation detected	Residual gamma	Residual gamma	Residual gamma
Measures	Total dose	Total dose	Total dose

   c. Operator maintenance

      (1) Cleaning

      (2) Decontaminating

      (3) Maintaining charge

      (4) Checking leakage rate

3. Radiac Detector Charger, PP1578A/PD

   a. Use

b. Components

c. Charging procedure

d. Maintenance

(1) Cleaning

(2) Testing

4. Correction Factor

$$CF = \frac{\text{Actual dose}}{\text{Scale reading}}$$

5. Ionization chamber dose rate instruments

a. Principle of operation

b. Radiacmeter, IM-174/PD

(1) Characteristics

(a) Use

(b) Measures

(c) Status

(d) Battery life

(e) Accuracy

(2) Operating controls

(a) Zero control

(b) Check switch

1. Zero

2. Check

3. Read

4. Elec cal

5. Linearity

(3). Operating procedure

(4) Maintenance

c. Radiacmeter, IM-174A/PD.

(1) Characteristics

(a) Use

(b) Measures

(c) Status

(d) Battery life

(e) Accuracy

(2) Operating controls

(a) Off-set control

(b) Check switch

(3) Operating procedure

(4) Maintenance

6. Geiger-Mueller instruments

a. Principle of operation

b. Radiac Set, AN/PDR-27( )

(1) Components

(2) Radiacmeter, IM-141

(a) Use

(b) Measures

(c) Detects

(d) Range

(e) Battery life

(f) Status

(3) Employment

(4) Maintenance

(5) Circuit check

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7. Practice problems.

1. A soldier has no dosimeter charger, but enters a contaminated area with a dosimeter which read 35 rad when issued to him. What dosage did he receive if his dosimeter (correction factor 1.05) read 90 rad when he left the contaminated area?

   ANSWER ____________

2. What would be the dose recorded on an IM-93 dosimeter if it were charged to zero and then exposed for 24 minutes at a distance of 50 centimeters from a 180 rhm source? Correction factor - 1.00.

   ANSWER ____________

3. A dosimeter has a correction factor of 0.90. If the dosimeter indicates a dose of 85 rad, what is the actual dose absorbed?

   ANSWER ____________

4. A dosimeter indicates 110 mrad when it is known that the actual absorbed dose is 120 mrad.

   a. What is the correction factor for this dosimeter?

      ANSWER ___________

   b. The accuracy should be 10%. Should the dosimeter be turned in for disposal?

      ANSWER ___________

5. A dosimeter (correction factor 1.2) when placed 1 meter from an unknown source for 24 minutes reads 83 mrad. What is the strength of the source in mrhm?

   ANSWER ___________

8. Solutions to practice problems.

1. a. Total Dose (SR) = Final Reading - Initial Reading

$= 90 \text{ rad} - 35 \text{ rad}$

$= 55$ rad on dosimeter.

b. $D = CF \times SR$

$D = 1.05 \times 55$

$D = \underline{57.75 \text{ rad}}$

2. $D = \frac{S}{d^2} \times T$

$D = \frac{180 \text{ rhm}}{(0.5 \text{ m})^2} \times \frac{24}{60} \text{ hr} = \underline{288 \text{ rad}}$

or, using $R = \frac{S}{d^2}$ and $D = R \times T$

$R = \frac{180 \text{ rhm}}{(0.5 \text{ m})^2} = 720 \text{ rad/hr}$

$D = 720 \text{ rad/hr} \times \frac{24}{60} \text{ hr} = \underline{288 \text{ rad}}$

3. $D = CF \times SR$

$D = 0.90 \times 85 \text{ rad} = \underline{76.5 \text{ rad}}$

4. a. $CF = \frac{D}{SR}$

$CF = \frac{120 \text{ mrad}}{110 \text{ mrad}} = \underline{1.09}$

b. $D - SR = 10$ mrad

$\frac{10}{120} = 0.08$ or 8%; <u>NO</u>

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5. $SR \times CF = D$

$83 \text{ mrad} \times 1.2 = 99.6 \text{ mrad}$

$S = \frac{D}{T} \times d^2$

$S = 99.6 \text{ mrad} \times \frac{60}{24} \text{ hr} \times (1 \text{ m})^2$

$S = \underline{249 \text{ mrhm}}$

or, using $R = \frac{D}{T}$ and $S = R \times d^2$,

$R = 99.6 \text{ mrad} \times \frac{60}{24} \text{ hr}$

$R = 249 \text{ mrad/hr}$

$S = 249 \text{ mrad/hr} \times (1 \text{ m})^2$

$S = \underline{249 \text{ mrhm}}$

STUDENT NO. ____________________

CLASS ____________________

DATE ____________________

INSTRUCTOR ____________________

SCORE ____________________

LABORATORY EXERCISE GEIGER-MUELLER INSTRUMENTS

II. Laboratory Exercise.

A. The class will be divided into groups of two. In each group one man will take the readings and the other will record data. The members of each group will change duties during the exercise in order that each person will have a chance to monitor with the instrument.

B. In the laboratory there are pieces of contaminated equipment in plastic bags. Each bag is lettered. The item in each bag MAY be contaminated with beta, or beta and gamma emitters.

C. Each group will monitor the bags to determine which equipment is contaminated; and if contaminated, determine the kind of radiation being emitted. **Indicate your answer by placing a check (✓) in** the proper column of the data sheet.

D. Safety regulations.

1. Handle the plastic bags only by the edges.

2. Inform the instructor if you find a rip or tear in any of the plastic bags.

3. After completing the exercise, the instrument man in each group will monitor the hands and the soles of the shoes of the other man in his group. He will then turn the instrument over to the man who will monitor him in the same manner. If <u>ANY</u> readings higher than the background are obtained, immediately inform the instructor.

DATA

DATA SHEET - GM INSTRUMENTS			
Article by Letter	Type of Contamination		
	B	B & G	NONE
A			
B			
C			
D			
E			
F			
G			
H			
I			
J			
K			
L			
M			
N			
O			
P			
Q			
R			
S			
T			

Questions. Circle the letter(s) corresponding to the correct answer(s).

1. The radiacmeter IM-141 of the AN/PDR-27(J) radiac set measures gamma radiation on four scales. They are

A. 0-½ mrad/hr.

B. 0-10 mrad/hr.

C. 0-100 mrad/hr.

D. 0-5 mrad/hr.

E. 0-50 mrad/hr.

F. 0-40 mrad/hr.

G. 0-0.5 rad/hr.

2. What types of radiation are detected or measured by the IM-141 radiacmeter of the AN/PDR-27(J) radiac set?

A. Alpha

B. Beta

C. Ultraviolet

D. Gamma

E. Neutrons

3. You are monitoring a pistol belt in a 0.1 mrad/hr background area. With the probe shield open you read 4 mrad/hr, with it closed you read 0.1 mrad/hr. You conclude that the pistol belt is .

A. contaminated with beta and gamma emitters.

B. contaminated with beta emitters only.

C. contaminated with gamma emitters only.

D. probably not contaminated.

4. The main reason a GM radiacmeter of the AN/PDR-27(J) radiac set is more sensitive than the IM-174/PD IC meter is that --

A. it uses electrical collection of ions principle

B. it has better construction

C. it makes use of gas amplification

D. it has thinner detector tubes

E. it detects beta radiation

5. You are monitoring a helmet in a 0.1 mrad/hr background area. With the shield on the probe open the outside reads 4.5 mrad/hr and the inside reads 3 mrad/hr; with the shield closed the outside and inside read 3 mrad/hr. From this you conclude that the outside is --

A. contaminated with beta and gamma emitters

B. contaminated with beta emitters only

C. contaminated with alpha emitters only

D. probably not contaminated

6. You are monitoring a pistol belt in the same area. With probe shield open you read 3 mrad/hr, with it closed you read 1 mrad/hr. You conclude that the pistol belt is --

A. contaminated with beta and gamma emitters

B. contaminated with beta emitters only

C. contaminated with gamma emitters only

D. probably not contaminated

7. You are performing a battery check of the IM-141 radiacmeter of the AN/PDR-27(J) radiac set. The meter needle stops to the left of the BATT mark on the dial. You should replace --

A. two batteries

B. one battery

C. three batteries

D. all the batteries

E. four batteries

8. The IM-141 radiacmeter of the AN/PDR-27(J) radiac set is --

A. an Army standard "A" personnel and equipment survey radiacmeter

B. the Army standard "B" personnel and equipment survey radiacmeter

C. the Army standard "B" area survey radiacmeter

D. the Army standard area survey radiacmeter

9. When using the IM-141 radiacmeter of the AN/PDR-27(J) radiac set on the 5 mrad/hr scale, the probe should be --

A. slanted to the surface but not touching the area being monitored

B. located in its carrying well at the rear of the AN/PDR-27(J)

C. touching and perpendicular to the surface being monitored

D. perpendicular to, but not touching the surface being monitored

STANDARDS FOR PROTECTION

DF170 - STANDARDS FOR PROTECTION

I. Reference: Title 10, Part 19 and 20, Code of Federal Regulations, paragraph 19.1-19.31, 20.1-20.5, 20.101-20.207, 20.401-20.601, Appendix B and C (see Appendix I, Radiological Safety Handbook).

II. Student Performance Objectives:

A. Definition of terms. Give a brief explanation of the following terms:

1. Byproduct material.
2. Special nuclear material.
3. Source material.
4. Ionizing radiation.
5. Occupational exposure to ionizing radiation.
6. Radiological protection officer.
7. Restricted area.
8. Unrestricted area.
9. Dose.
10. Rad.
11. Rem.
12. RBE.

B. Dose limits and dose recording regulations:

1. Give a brief explanation of each of the following areas:

a. Dosage to minors.

b. Quarterly reporting.

c. Occupational dose.

d. Use of equation 5(n-18).

e. Calculation of working overall dosage.

f. Permissible level, if an unused backlog is available (3rem/quarter).

g. No records maintained level and why.

h. Army's record maintenance.

i. Emergency dosage.

j. Medical diagnosis and therapy.

2. Forms used:

   a. NRC Form 4.

   b. NRC Form 5.

   c. DD Form 1141.

3. Importance of particle size and appendix B of 10 CFR 20:

   a. General population restriction.

   b. Radiation workers occupation of area.

   c. Exceeding the acceptable limits for any type of worker.

4. Dose limitations at edge of restricted area from sealed sources.

C. Explain the following areas of a radiation safety program:

1. Surveys.
2. Personnel monitoring.
3. Caution signs.
4. Labels.
5. Signals.
6. Instruction to personnel.
7. Posting of notices to employees.
8. Proper storage.
9. Proper waste disposal.

D. Explain the dose rate requirement required for radiation and high radiation areas:

E. Define the use of the following signs:

1. Radiation area.

2. High radiation area.

3. Airborne radioactive area.

4. Radioactive materials.

F. Give each of the following items required:

1. Instructions to personnel using radiation areas (5 items).

2. Posting of notices to employees (4 items).

3. Reports to employees (present employees and former employees).

4. NRC reporting requirements (3 types of reports).

5. Responsibility for radioactive materials at the installation level.

6. Records, reports, and notifications in a safety program.

III. Handouts. Vu-Graphs used in DF170.

A. Code of Federal regulations.

TITLE 10		Atomic Energy
	Part 19	Notices, Instructions and Reports to Workers; Inspections
	Part 20	Standards for Protection Against Radiation
	Part 30	Licensing of Byproduct Material General License Specific License
	Part 40	Control of Source Material
	Part 70	Control of Special Nuclear Material

B. Byproduct Material. Any nuclear material (except special) yielded by exposure to the process of producing or utilizing special material - reactor byproducts (either fission products or material produced by induced reactions).

C. Special Nuclear Material.

1. Plutonium, Uranium-233, uranium enriched in isotopes 233 or 235, or any other material determined by NRC.

2. Any material artificially enriched by 1. above.

3. Does <u>not</u> include source material.

D. Source Material. Any material except special nuclear material which contains by weight, 1/20 of 1% (0.05%) or more of uranium, thorium, or any combination thereof.

E. Terms From AR 40-14.

1. Ionizing radiation. Electromagnetic or particulate radiation, which may cause ionization within the cells or tissue of the body. For the purpose of this regulation, alpha and beta particles, gamma rays, X-rays, and neutrons are examples of types of ionizing radiation.

2. Occupational exposure to ionizing radiation. An exposure incurred as a result of an individual's employment or duties. Occupational exposure shall not be deemed to include the exposure of an individual to sources of ionizing radiation for the purpose of medical or dental diagnosis or therapy.

3. User. The activity, section, division, or other organizational unit which has been assigned responsibility for the use, operation, or storage of radiation sources.

F. Radiation Sources. Material, equipment, or devices which generate or are capable of generating ionizing radiation including:

1. Natural-occurring radioactive materials.

2. Byproduct materials.

3. Source materials.

4. Special nuclear materials.

5. Fission products.

6. Materials containing induced or deposited radioactivity.

7. Nuclear reactors.

8. Radiographic and fluoroscopic equipment.

9. Particle generators and accelerators.

10. Radiofrequency generators such as certain klystrons and magnetrons which produce X-rays.

G. Radiation Protection Officer. An individual designated by the commander to provide consultation and advice on the degree of hazards associated with ionizing radiation and the effectiveness of measures to control these hazards. This individual shall be technically qualified by virtue of education, military training, and/or professional experience to assure a capability commensurate with the assignment.

H. Definition of terms on areas.

1. Restricted area. Any area that the access to is controlled by the licensee for protection against radiation. Shall not include residential quarters. Separate room or rooms in residential quarters may be set apart as a restricted area.

2. Unrestricted area. Any area that the access to is <u>not</u> controlled by licensee, and any area used for residential quarters.

3. A room or series of rooms in a house may be restricted but not the whole house.

I. Dose.

1. The quantity of radiation absorbed, per unit of mass by the body, or any portion of the body.

2. Rad. The dose of any ionizing radiation to body tissue in terms of the energy absorbed per unit mass of the tissue (100 erg/gm).

J. Rem.

1. Dose of any ionizing radiation to body tissues in terms of its estimated biological effect relative to a dose of 1 roentgen of X-rays.

2. Equivalent to 1 rem:

1 roentgen -- gamma or X-ray.
1 rad ------- gamma, beta, or X-ray.
0.1 rad ------- neutrons or high energy protons.
0.05 rad ------- particles heavier than protons with sufficient energy to reach the eyes.

K. Maximum permissible dose.

Records Maintained				No Records Maintained
Part of Body Exposed	Quarter	Year	Occupation Dose	
1. Whole body	3	12	5(n-18)	1.25
2. Head & trunk				
3. Blood forming organs				
4. Lens of eye				
5. Gonads				
1. Hands and forearms	18.75	75		18.75
2. Feet and ankles				
1. Skin of whole body	7.5	30		7.5

Minors - 10% of no records maintained.

L. Airborne radioactive materials. Any material dispersed in the air.

Gases	Natural Formless State
Particles	
Solid	
Dust	Submicroscopic - microscopic
Fumes	Less than 1 micron
Smoke	Less than 0.5 micron
Liquid	
Fog	Submicron droplets
Mist	0.1 - 25 microns

Micron = 0.001 mm
Submicron = less than a micron

M. Effects of particles size.

Micron	Retention
<1	Large percent exhaled
1-10	Large percent retained
10-50	Usually trapped in the upper respiratory tract

N. Unrestricted area.

DOSE RATE AT EDGE OF RESTRICTED AREA

Exposure	MPE	Dose
1 hr	2 mrad/hr	2 mrem
Continuous exposure		
7 consecutive days	0.59 mrad/hr	100 mrem
1 year	0.059 mrad/hr	0.5 rem

O. Precautionary measures. Precautionary measures that are required to be carried out.

1. Surveys.
2. Personnel monitoring.
3. Caution signs.
4. Labels.
5. Signals.
6. Instruction of personnel.
7. Posting of notices to employees.
8. Proper storage.
9. Proper waste disposal.

P. Radiation.

1. Radiation area. Any area in which there exists radiation at such levels that a major portion of the body could receive a dose in

1 hour ------------------------------------ 5 mrem

5 consecutive days ------------------------------ 100 mrem

2. High radiation area. Any area in which there exists radiation at such levels that a major portion of the body could receive a dose in 1 hour — greater than 100 mrem.

Q. Caution Signs.

1. Caution - radiation area.

2. Caution - high radiation area.

3. Caution - airborne radioactive area.

4. Caution - radioactive material.

   Quantity
   Kind
   Date of measurement

Labels or signs are not required if they do not exceed the following:

a. The concentration in water is not greater than the limits specified in annex B, table 1, column 2, 10 CFR20.

b. For laboratory containers used transiently in the laboratory procedures, if the attendant is present.

c. Room or area with a sealed source if the radiation level 1 foot from the surface is less than 5 mrad/hr.

d. Rooms or areas in hospitals due to presence of patients with radioactive material, provided there are attendants present to prevent the exposure of other individuals in excess of the limits.

e. Rooms or areas containing material less than 8 hours provided —

(1) They are constantly attended.

(2) That precautionary measures are taken to prevent over-exposure of personnel.

(3) That the area is subject to licensee's control.

R. Records. Each licensee shall maintain the following:

1. Form NRC 4 (history).

2. Form NRC 5 (current exposure).

3. Results of surveys.

4. Record of waste disposal.

   a. Sanitary sewage systems.

   b. Burial in soil.

5. Receipt and transfer of all material.

S. NRC Reporting.

Immediate notification

The Manager of NRC Operations Office for the area will be notified by telephone or telegram when

1. Exposure of any individual to

   25 rems whole body
   150 rems skin of whole body
   375 rems, feet, ankles, hands, and forearms

2. Loss of one working week of facilities.

3. Damage to property in excess of $100,000.

4. Concentrations released that exceed 5,000 times the limits specified.

5. Any loss or theft of licensed material.

T. Twenty-four-hour notification.

1. Exposure of any individual to

   5 rems whole body
   30 rems skin of whole body
   75 rems feet, ankles, hands, forearms

2. Loss of 1 working day of facilities.

3. Damage to property in excess of $1,000.

4. Concentrations released exceeding 500 times the limits specified.

Thirty-day reports.

Each incident involving licensed material which results in excess of any applicable limits set forth in NBC regulations.

U. Instructions of personnel using radiation areas:

1. Storage, transfer or use of radioactive materials or of radiation in any portion of the area.

2. Where radiation is and in what amount.

3. Safety problems and health protection problems associated with exposure.

4. Procedures to minimize exposure.

5. Purpose and function of protective license.

6. Applicable provisions of regulations and license covering protection of personnel from exposure.

7. Their responsibility to report promptly any conditions which may lead to a violation.

8. Reports of radiation exposure which employees may request.

9. Appropriate responses to warnings.

IV. Posting of notices to employees.

1. Copy of Title 10, Parts 19 and 20 CFR.

2. Copy of license, license conditions, or documents incorporated into the license by reference.

3. Copy of operating procedures.

4. Notice to Employees, Form NRC 3, shall be conspicuously posted in a sufficient number of places in every establishment where employees are employed in activities — to observe on their way to or from place of employment.

5. Any notice of violation involving radiological working conditions, proposed imposition of civil penalties, and any response.

6. Licensee may state when these are available if posting is impractical.

7. Any notice of violation must be posted within 2 days of receipt and replies by the licensee must be posted within 2 days after receipt or after it is sent and remain until corrected or for 5 days, whichever is longer.

W. Reports to Employees.

1. Former employees: Upon request, a report of exposure to radiation, as shown by the licensee's records, is to be furnished with 30 days. The report must be written and comply with paragraph 19.13, 10 CFR 19.

2. Present employees. Upon request, the licensee shall advise the employee annually of his exposure to radiation as shown in the records. In cases of over exposure, the employees will be notified in accordance with paragraph 19.13 10 CFR 19.

FORM NRC-4
(9-60)

Form approved.
Bureau of Budget No 38-R119.
Expiration Date: June 30, 1961.

U. S. NUCLEAR REGULATORY COMMISSION

OCCUPATIONAL EXTERNAL RADIATION EXPOSURE HISTORY

See Instructions on the Back

IDENTIFICATION

1. NAME (PRINT—LAST, FIRST, AND MIDDLE)	2. SOCIAL SECURITY NO
3. DATE OF BIRTH (MONTH, DAY, YEAR)	4. AGE IN FULL YEARS (N)

OCCUPATIONAL EXPOSURE—PREVIOUS HISTORY

5. PREVIOUS EMPLOYMENTS INVOLVING RADIATION EXPOSURE—LIST NAME AND ADDRESS OF EMPLOYER	6. DATES OF EMPLOYMENT (FROM—TO)	7. PERIODS OF EXPOSURE	PREVIOUS DOSE HISTORY: 8. WHOLE BODY (REM)	PREVIOUS DOSE HISTORY: 9. INSERT ONE. RECORD OR CALCULATED
10. REMARKS		11. ACCUMULATED OCCUPATIONAL DOSE—TOTAL		

SAMPLE

13. CALCULATIONS—PERMISSIBLE DOSE

WHOLE BODY

(A) PERMISSIBLE ACCUMULATED DOSE = 5(N-18) = ______________ REM

(B) TOTAL EXPOSURE TO DATE (FROM ITEM 14) = ______________ REM

(C) PERMISSIBLE DOSE = ______________ REM

12. CERTIFICATION: I CERTIFY THAT THE EXPOSURE HISTORY LISTED IN COLUMNS 5, 6, AND 7 IS CORRECT AND COMPLETE TO THE BEST OF MY KNOWLEDGE AND BELIEF.

____
EMPLOYEE'S SIGNATURE DATE

14. NAME OF LICENSEE

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INSTRUCTIONS FOR PREPARATION OF FORM NRC-4

This form or a clear and legible record containing all the information required on this form must be completed by each licensee of the Nuclear Regulatory Commission who, pursuant to Section 20.101, proposes to expose an individual to a radiation dose in excess of the amounts specified in Section 20.101(a) of the regulations in Part 20, "Standards for Protection Against Radiation," 10 CFR. The requirement for completion of this form is contained in Section 20.102 of that regulation. The information contained in this form is used for estimating the accumulated occupational dose of the individual for whom the form is completed. A separate form shall be completed for each individual to be exposed to a radiation dose in excess of the limits specified in Section 20.101(a) of the Part 20 regulations.

Listed below by item are instructions and additional information directly pertinent to completing this form:

Identification

Item 1. Self-explanatory.
Item 2. Self-explanatory except that, if individual has no social security number, the word "none" shall be inserted.
Item 3. Self-explanatory.
Item 4. Enter the age in full years. This is called "N" when used in calculating the Permissible Dose. N is equal to the number of years of age of the individual on his last birthday.

Occupational Exposure

Item 5. List the name and address of each previous employer and the address of employment. Start with the most recent employer and work back.

Include only those periods of employment since the eighteenth birthday involving occupational exposure to radiation. For periods of self-employment, insert the word "self-employed."

Item 6. Give the dates of employment.
Item 7. List periods during which occupational exposure to radiation occurred.
Item 8. List the dose recorded for each period of exposure from records of previous occupational exposure of the individual as calculated under Section 20.102. Dose is to be given in rem.

"Dose to the whole body" shall be deemed to include any dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of eye.

Calculated Dose

Item 9. After each entry in Item 8 indicate in Item 9 whether dose is obtained from records or calculated in accordance with Section 20.102.
Item 10. Self-explanatory.

Total Accumulated Occupational Dose (Whole Body)

Item 11. The total for the whole body is obtained by summation of all values in Item 8.

Certification

Item 12. Upon completion of the report, the employee must certify that the information in Columns 5, 6, and 7 is accurate and complete to the best of his knowledge. The date is the date of his signature.

Calculations

Item 13. The lifetime accumulated occupational dose for each individual and the permissible dose under Section 20.101(b) are obtained by carrying out the following steps: The value for N should be taken from Item 4. Subtract 18 from N and multiply the difference by 5 rem. (For example, John Smith, age 32; N=32, MPD=5(32-18)=70 rem.) Enter total exposure to date from Item 11. Subtract (b) from (a) and enter the difference under (c). The value in (c) represents the dose to the whole body to which that individual can be exposed in accordance with Section 20.101(b). This value for permissible dose is to be carried forward to Form NRC-5, "Current Occupational External Radiation Exposure (Whole Body)."
Item 14. Self-explanatory.

U.S. GOVERNMENT PRINTING OFFICE 1966-O-585288

FORM NRC-5
(5-62)

Form approved.
Bureau of Budget No. 38-R120.1

U. S. NUCLEAR REGULATORY COMMISSION

CURRENT OCCUPATIONAL EXTERNAL RADIATION EXPOSURE

See Instructions on the Back

IDENTIFICATION

1. NAME (PRINT—Last, first, and middle)	2. SOCIAL SECURITY NO.
3. DATE OF BIRTH (Month, day, year)	4. NAME OF LICENSEE

OCCUPATIONAL EXPOSURE

5. DOSE RECORDED FOR (Specify: Whole body; skin of whole body; or hands and forearms, feet and ankles.)	6. WHOLE BODY DOSE STATUS (rem)	7. METHOD OF MONITORING (e.g., Film Badge—FB; Pocket Chamber—PC; Calculations—Calc.) X OR GAMMA ______ BETA ______ NEUTRONS ______

8. PERIOD OF EXPOSURE (From—to)	DOSE FOR THE PERIOD (rem)				13. RUNNING TOTAL FOR CALENDAR QUARTER (rem)
	9. X OR GAMMA	10. BETA	11. NEUTRON	12. TOTAL	

SAMPLE

LIFETIME ACCUMULATED DOSE

14. PREVIOUS TOTAL (rem)	15. TOTAL QUARTERLY DOSE date rem	16. TOTAL ACCUMULATED DOSE (rem)	17. PERM. ACC. DOSE 5(N-18) (rem)	18. UNUSED PART OF PERMISSIBLE ACCUMULATED DOSE (rem)
		238		

INSTRUCTIONS FOR PREPARATION OF FORM NRC-5

The preparation and safekeeping of this form or a clear and legible record containing all the information required on this form is required pursuant to Section 20.401 of "Standards for Protection Against Radiation," 10 CFR 20, as a current record of occupational external radiation exposures. Such a record must be maintained for each individual for whom personnel monitoring is required under Section 20.202. Note that a separate Form NRC-5 is to be used for recording external exposure to (1) the whole body, (2) skin of whole body, (3) hands and forearms; or (4) feet and ankles, as provided by Item 5 below.

Listed below by item are instructions and additional information directly pertinent to completing this form.

Identification

Item 1. Self-explanatory

Item 2. Self-explanatory except that, if individual has no social security number, the word "none" shall be inserted.

Item 3. Self-explanatory.

Item 4. Self-explanatory

Occupational Exposure

Item 5. "Dose to the whole body" shall be deemed to include any dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of eye. Unless the lenses of the eyes are protected with eye shields, dose recorded as whole body dose should include the dose delivered through a tissue equivalent absorber having a thickness of 300 mg/cm² or less When the lenses of the eyes are protected with eye shields having a tissue equivalent thickness of at least 700 mg/cm², dose recorded as whole body dose should include the dose delivered through a tissue equivalent absorber having a thickness of 1,000 mg/cm² or less.

Dose recorded as dose to the skin of the whole body, hands and forearms, or feet and ankles should include the dose delivered through a tissue equivalent absorber having a thickness of 7 mg/cm² or less. The dose to the skin of the whole body, hands and forearms, or feet and ankles should be recorded on separate forms unless the dose to those parts of the body has been included as dose to the whole body on a form maintained for recording whole body exposure.

Item 6. This item need be completed only when the sheet is used to record whole body exposures and the licensee is exposing the individual under the provisions of Paragraph 20.101(b) which allows up to 3 rems per quarter to the whole body. Enter in this item the unused part of permissible accumulated dose taken from previous records of exposure, i.e., Item 18 of the preceding Form NRC-5 or Item 13 of Form NRC-4 if the individual's exposure during employment with the licensee begins with this record

Item 7. Indicate the method used for monitoring the individual's exposure to each type of radiation to which he is exposed in the course of his duties. Abbreviations may be used.

Item 8. Doses received over a period of less than a calendar quarter need not be separately entered on the form provided that the licensee maintains a current record of the doses received by the individual which have not as yet been entered on the form. The period of exposure should specify the day the measurement of that exposure was initiated and the day on which it was terminated. For example, if only quarterly doses are entered, the period of exposure for the first calendar quarter of 1962 might be taken as running from Monday, January 1, 1962, through Friday, March 30, 1962, and would be indicated in this item as Jan. 1, 1962–Mar. 30, 1962. If weekly doses are entered, a film badge issued Monday morning, January 1, 1962, and picked up Friday, January 5, 1962, would be indicated as Jan. 1, 1962–Jan. 5, 1962.

Items 9, 10 and 11. Self-explanatory. The values are to be given in rem. All measurements are to be interpreted in the best method known and in accordance with Paragraph 20.4(c). Where calculations are made to determine dose, a copy of such calculations is to be maintained in conjunction with this record. In any case where the dose for a calendar quarter is less than 10% of the value specified in Paragraph 20.101(a), the phrase "less than 10%" may be entered in lieu of a numerical value.

Item 12. Add the values under Items 9, 10 and 11 for each period of exposure and record the total. In calculating the "Total" any entry "less than 10%" may be disregarded.

Item 13. The running total is to be maintained on the basis of calendar quarters. Paragraph 20.3(a)(4) defines calendar quarter. No entry need be made in this item if only calendar quarter radiation doses are recorded in Items 9, 10, 11 and 12.

Lifetime Accumulated Dose (Whole Body)

NOTE: If the licensee chooses to keep the individual's exposure below that permitted in Paragraph 20.101(a), Items 14 through 18 need not be completed. However, in that case the total whole body dose for each calendar quarter recorded in Item 13 (or in Item 12 if quarterly doses are entered in Item 12) should not exceed 1¼ rem.

If an individual is exposed under the provisions of Paragraph 20.101(b), complete Items 14 through 18 at the end of each calendar quarter and when the sheet is filled. Values in Item 13, when in the middle of a calendar quarter, and values in Item 18, must be brought forward to next sheet for each individual.

Item 14. Enter the previous total accumulated dose from previous dose records for the individual (e.g., from Item 16 of Form NRC-5 or Item 11 Form NRC-4). The total occupational radiation dose received by the individual must be entered in this item, including any occupational dose received from sources of radiation not licensed by the Commission. If the individual was exposed to sources of radiation not licensed by the Commission during any calendar quarter after completing Form NRC-4 and personnel monitoring equipment was not worn by the individual, it should be assumed that the individual received a dose of 1¼ rems during each such calendar quarter.

Item 15 Enter the total calendar quarter dose from Item 13 (or from Item 12 if quarterly doses are entered in Item 12) and the date designating the end of the calendar quarter in which the dose was received (e.g., March 30, 1962).

Item 16. Add Item 14 and Item 15 and enter that sum

Item 17. Obtain the Permissible Accumulated Dose (PAD) in rem for the WHOLE BODY. "N" is equal to the number of years of age of the individual on his last birthday Subtract 18 from N and multiply the difference by 5 rem (e.g., John Smith, age 32: N=32, PAD=5(32−18)=70 rem).

Item 18. Determine the unused part of the PAD by subtracting Item 16 from Item 17. The unused part of the PAD is that portion of the Lifetime Accumulated Dose for the individual remaining at the end of the period covered by this sheet

U.S. GOVERNMENT PRINTING OFFICE 1962 OF—613647

RECORD OF OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

FOR INSTRUCTIONS, SEE REVERSE OF SHEET.

1. IDENTIFICATION NUMBER	2. NAME (*Last, first, middle initial*)	3. SOCIAL SECURITY NUMBER	4. RANK/RATE TITLE OF POSITION	5. DATE OF BIRTH (*Day, month, year*)
	SAMPLE			

PLACE WHERE EXPOSURE OCCURRED	PERIOD OF EXPOSURE		DOSE THIS PERIOD (rem) 1. *Method of monitoring is presumed to be film badge reading unless otherwise specified under item 16, "REMARKS."*				ACCUMULATED DOSE (rem)		INITIAL
ACTIVITY 6	FROM (*Day-Mo-Yr*) 7	TO (*Day-Mo-Yr*) 8	SKIN DOSE (*Soft*) 9	GAMMA AND X-RAY 10	NEUTRON 11	TOTAL THIS PERIOD 12	TOTAL LIFETIME 13	PERMISSIBLE LIFETIME 5(N-18) 14	PERSON MAKING ENTRY 15

16. REMARKS (*Continue on additional sheet if necessary*)

TO BE RETAINED PERMANENTLY IN INDIVIDUAL'S MEDICAL RECORD

DD FORM 1 MAY 67 1141 PREVIOUS EDITIONS ARE OBSOLETE.

INSTRUCTIONS FOR PREPARATION OF DD FORM 1141

ITEM

1. Enter file, service, badge, check, or clock number by which individual is currently identified.

2. Enter last name, first name, and middle initial. If the combination of last name and first name exceeds 19 spaces, enter last name and initials only.

3. Enter Social Security number.

4. Enter in not more than 10 spaces, rank, rate, grade, title or position that the individual is currently holding. Use standard service abbreviations, e. g., CAPT; MC; HMCS; HM1; SSGT; LCPL, etc. Abbreviate civilian occupation titles as necessary; e. g., Radiological Physicist to Rad Physic, Radiation Physiologist to Rd Physiol; Electrical Welder to Elec Wldr; etc.

5. Enter date of birth by day, month, and year, e. g., 21 Sep 1918.

6. Enter name of activity or unit.

7 and 8. "Period of Exposure." Enter the day, month, and year, e. g. 1 Oct 62.

7. Enter the day, month, and year exposure period began.

8. Enter day, month, and year exposure period ended.

9 through 12. "Dose This Period." Enter radiation dose received this period to three decimal places, e. g., 02.345 rem. All entries shall be made using five digits including zeros as necessary.

9. Enter skin dose *(soft)* which includes low energy gamma and x-ray of less than 20 KEV effective energy and beta radiation. Total skin dose is the visual addition of columns 9 and 12.

10. Enter gamma and x-ray dose greater than 20 KEV effective energy in rem.

11. Enter Neutron dose in rem.

12. Enter sum of items 10 and 11.

13. Add item 12 to previous item 13, enter total in item 13.

14. Enter permissible dose calculated from the age formula 5(N-18) rem, where N equals the present age in years.

15. Recorder certify entries by initialling.

16. Enter other pertinent information such as known exposure from internally deposited radioactive material or from any external radioactive sources. Describe briefly any activity or assignment bearing a potential for exposure and estimate dose-time relationships, if feasible. If this form is used for other than whole body and skin of whole body, specify the use: i. e., hands and forearms, feet and ankles, thyroid, etc. When recorded dose is not obtained from film badge readings, specify whether estimates were obtained from pocket dosimeters, area or air monitoring, bioassay, etc.

NOTE:

This record is required on all individuals who are employed by or are members of the Armed Forces and who have been or are being occupationally exposed to ionizing radiation. It shall be the responsibility of each activity of the Department of Defense having personnel so exposed to initiate and maintain this record in accordance with AR 40-14/BUMEDINST 6150.18 series/AFR 161-8/DSAR 4145.24.
(29 Sept. 1966)

LIST OF REFERENCES

1. Code of Federal Regulations.

   a. Title 10, Part 19, Notices, Instructions and Report of Workers; Inspections.

   b. Title 10, Part 20, Standards for Protection Against Radiation.

   c. Title 10, Part 30, Licensing of Byproduct Material.

2. Technical Bulletins.

   a. NBS Handbook 73, Protection Against Radiation from Sealed Gamma Sources.

   b. NBS Handbook 92, Safe Handling of Radioactive Materials.

   c. TB Sig 225, Identification and Handling of Radioactive Signal.

3. Army Regulations.

   a. AR 40-14, Control and Recording Procedures Occupational Exposure to Ionizing Radiation.

   b. AR 55-55, Transportation of Radioactive and Fissile Materials Other than Weapons.

   c. AR 755-15, Disposal of Unwanted Radioactive Material.

4. Training Circulars and Field Manuals.

   a. FM 3-15, Nuclear Accident Contamination Control.

   b. TM 3-261, Handling and Disposal of Unwanted Radioactive Material.

V. Problems.

1. In dealing with regulations concerning radioactive materials three terms are used: Byproduct Materials, Special Nuclear Material and Source Material. To what type of material does each term refer.

2. What total amount of radiation could a man 30 years of age have accumulated if records have been maintained on his exposure since age 18?

3. A man 27 years of age comes to you for employment. His work records show he has received 41.3 rem of radiation. What total dose may he receive in addition to the dose he has accumulated? What amount of this total could he receive in the first quarter he works for you?

4. Upon hiring a new employee you find he has no past history as a radiation worker but he has worked in the vicinity of radiation before. He is 21 years old. What dose may he receive during this year?

5. Determine whether the areas listed should be restricted or unrestricted. All values are for air.

a.	^{210}Bi	Sol	9×10^{-10} μc/ml
b.	^{60}Co	Sol	7×10^{-9} μc/ml
c.	^{140}La	Sol	4.2×10^{-9} μc/ml
d.	^{32}P	Ins	9×10^{-10} μc/ml
e.	^{3}H	Sol	6×10^{-7} μc/ml
f.	^{111}Ag	Sol	4×10^{-9} μc/ml
g.	^{95}Zr	Ins	8×10^{-9} μc/ml
h.	^{90}Y	Sol	3×10^{-8} μc/ml
i.	^{46}Sc	Ins	9.0×10^{-10} μc/ml
j.	^{186}Re	Ins	6.0×10^{-9} μc/ml

6. What forms should be acquired or maintained on radiation work?

7. What is the maximum permissible dose at the edge of restricted areas when the exposure is limited to

a. 1 hour

b. 1 year

c. To constitute a high radiation area the dose which may be received in 1 hour must be what amount?

8. There are three types of reports required by NRC. The type of the report depends upon the severity of the accident or incident. What are these reports?

9. The following isotopes are in air in the indicated concentrations. Are the limits for a restricted area exceeded?

^{82}Br	5×10^{-7} µc/ml	Soluble
^{246}Cm	1×10^{-12} µc/ml	Soluble
^{35}S	9×10^{-8} µc/ml	Soluble

10. In an accident, two millicuries of ^{14}C, as CO_2, were released in a room 10 x 12 x 3 meters. Assuming that the CO_2 is evenly distributed in the air space of this room, does the concentration exceed the maximum permissible concentration in Title 10, Part 20, App B?

11. Given concentration in air of

^{198}Au	2×10^{-9} μc/ml	Soluble
^{122}Sb	4×10^{-9} μc/ml	Soluble
Unknown	4×10^{-15} μc/ml	Soluble

Should this area be restricted or unrestricted?

12. You are monitoring in an unrestricted area for an airborne concentration of isotopes. The following data is taken:

Concentration A	^{36}Cl	5×10^{-10} μCi/ml	Sol
Concentration B	^{14}C	3×10^{-8} μCi/ml	Sol
Concentration C	^{131}I	1×10^{-11} μCi/ml	Sol
Concentration D	^{18}F	4×10^{-8} μCi/ml	Sol

Is the airborne concentration in this room low enough to be classified as an unrestricted area? (General population can move freely with no radiation restrictions.)

VI. Solutions to Problems.

1. a. Byproduct Material - Any nuclear material (except special) yielded by exposure to the process of producing or utilizing special material - reactor byproduct (<u>either fission products or material produced by induced reactions</u>).

b. Special Nuclear Material - Plutonium, Uranium-233, Uranium enriched in isotopes ^{233}U or ^{235}U, or any other material determined by NRC (<u>weapons materials</u>).

c. Source Material - Any material except special nuclear material which contains by weight 1/20 of 1% (0.05%) or more of uranium, thorium, or any combination thereof (<u>these are the ores</u>).

2. The governing factor is 5(n - 18)

n = 30 years.

5(30 - 18)

5(12)

<u>60 rem of radiation</u>

3. Dose received to this date 41.3

The governing factor is $5(n-18)$ n = 27 years.

$$5(27 - 18)$$

$$5(9) = 45 \text{ rem}$$

$$45 \text{ rem} - 41.3 \text{ rem} = \underline{\underline{3.7 \text{ rem}}}$$

Since he has 3.7 rem remaining exposure; he could receive 3 rem the first quarter (if necessary).

4. You must assume he has received the maximum dose since he was 18 years old.

Therefore, he may only receive <u>5 rem</u> during this year.

5. a. Restricted.
   b. Unrestricted.
   c. Unrestricted.
   d. Unrestricted.
   e. Restricted.
   f. Unrestricted.
   g. Restricted.
   h. Restricted.

i. Restricted.

j. Unrestricted.

6. NRC Form 4 - Personal history

NRC Form 5 - Current Occupational External Radiation Exposure

DD Form 1141 (for military) - Record of Exposure to Ionizing Radiation

7. a. 2 mrem

b. 0.5 rem

c. Greater than 100 mrem

8. a. Immediately

b. Twenty-four hour notification

c. Thirty-day report.

9. $$\frac{C_A}{MPC_A} + \frac{C_B}{MPC_B} + \frac{C_C}{MPC_C} \leqq 1$$

$$\frac{5 \times 10^{-7}}{1 \times 10^{-6}} + \frac{1 \times 10^{-12}}{5 \times 10^{-12}} + \frac{9 \times 10^{-8}}{3 \times 10^{-7}} \leqq 1$$

$0.5 + 0.2 + 0.3 = 1$

Within the limits of a restricted area (barely).

SAFE HANDLING AND STORAGE OF RADIOACTIVE MATERIAL

DF180

10. a. Volume of room in cm^3

$$10 \text{ m} \times 12 \text{ m} \times 3 \text{ m} \times \frac{10^6 \text{ml}}{\text{m}^3} = 3.6 \times 10^8 \text{ ml}$$

b. 2 millicuries = 0.002 curies = 2×10^3 µc

therefore $\frac{2 \times 10^3 \ \mu c}{3.6 \times 10^8 \text{ ml}} = 5.555 \times 10^{-6}$ µc/ml

c. MPC for ^{14}C in air = 5×10^{-5} µc/ml

<u>5.55×10^{-6} µc/ml does not exceed MPC</u>

11. $$\frac{C_A}{MPC_A} + \frac{C_B}{MPC_B} + \frac{C_c}{MPC_c} \leq 1$$

$$\frac{2 \times 10^{-9}}{1 \times 10^{-8}} + \frac{4 \times 10^{-9}}{6 \times 10^{-9}} + \frac{4 \times 10^{-15}}{2 \times 10^{-14}}$$

$$0.2 + 0.667 + 0.2 = 1.067 > 1$$

$\therefore$ This must be a restricted area. (MPC_c from Footnote 2c at end of Appendix B.)

12. $$\frac{C_A}{MPC_A} + \frac{C_B}{MPC_B} + \frac{C_C}{MPC_C} + \frac{C_D}{MPC_D} \leq 1$$

From Table II. Column I - MPC's are taken.

$$\frac{5x10^{-10}\mu Ci/ml}{1x10^{-8}\mu Ci/ml} + \frac{3x10^{-8}\mu Ci/ml}{1x10^{-7}\mu Ci/ml} + \frac{1x10^{-11}\mu Ci/ml}{1x10^{-10}\mu Ci/ml} + \frac{4x10^{-8}\mu Ci/ml}{2x10^{-7}\mu Ci/ml}$$

$$5x10^{-2} + 3x10^{-1} + 1x10^{-1} + 2x10^{-1}$$

$$0.05 + 0.3 + 0.1 + 0.2 = 0.65 < 1$$

Therefore it is unrestricted and the general population can enter.

DF180, SAFE HANDLING AND STORAGE OF RADIOACTIVE MATERIAL

I. Discussion and References.

A. Discussion.

1. The safe handling and storage of radioactive materials require special techniques and protective measures. The purpose of the techniques and protective measures is:

   a. to prevent ingestion, inhalation, and entry by any mode of radioisotopes into the body;

   b. to reduce the amounts of external radiation to or below the permissible levels; and

   c. to minimize the external and the internal exposures.

2. In order to control the external exposure we employ a sensible and concurrent utilization of four basic techniques of exposure control.

   a. distance

   b. time

   c. shielding

   d. quantity

3. Two general techniques are employed to control or reduce internal exposure. These are:

   a. dilution and dispersion.

   b. containment and concentration.

   In order to employ these techniques, a number of handling methods are used. The method of handling becomes more complex as the quantity and potential hazard of the radioactive material increases. These methods are broken into four general categories: direct viewing, shielding barrier, closed cell, and underwater.

   c. A third method of control could be labeled "Delay and Decay." This method would control the material until it has decayed beyond limits of considering it radioactive.

4. When storing radioactive materials, the complexity of the facility depends upon the quantity and type of materials being stored. A number of things which should be considered are:

   a. marking the storage area.

   b. marking of individual sources.

   c. distribution of radioactive material.

   d. shielding of subdivided amounts.

   e. time required to remove and replace material.

   f. ventilation (if material is gaseous or has gaseous daughter products).

   g. dose rate to individuals outside the storage area (nonradiation workers in particular).

   h. personnel monitoring devices (dose and dose rate) for personnel entering the storage area.

5. In order to plan for the safe handling and storage of radioactive material one must know the source strength of the material. To determine the source strength of a given amount of material, knowing its activity, one may use the expression

$$S_\gamma = 0.56\,nCE$$

where

S = source strength in rhm

c = number of curies

E = the energy of the gamma photon emitted by the radioactive material

n = the fraction of time a gamma photon of energy E is emitted

If more than one energy gamma photon is emitted, the contribution of each to the source strength must be considered.

$$S_\gamma = 0.56\ C\ \Sigma nE$$

B. Some Additional References:

1. NBS Handbook 73.

2. Chapter 7, Nuclear Instruments and Their Uses, Volume I, edited by A. H. Snell.

3. "Safe Handling of Radioisotopes," Safety Series No. 1, International Nuclear Regulatory Commission.

II. Lesson Objectives and Notes:

A. Discuss the methods of safe handling and storage of radioactive material.

B. Calculation of Source Strength.

III. Handouts: None

IV. Problems:

Class and Home Study Problems.

1. What is the source strength of 7 curies of Cobalt-57?

2. What is the source strength of 120 curies of Gallium-72?

3. What would be the dose rate 25 cm from a 420 mc source of Arsenic-74?

4. What dose would you receive 230 cm from a 720 mc source of Manganese-56 in $7\frac{1}{2}$ hours?

5. A reading of 270 mrad/hr is observed 300 cm from a Ruthenium-103 source. What is its activity?

6. What is the minimum distance personnel can work from an unshielded 5-curie Co-60 source, if they work 8 hours per day 5 days a week? (Weekly MPE = 300 mrem.)

7. What is the maximum permissible time a worker can be exposed to an unshielded 10-curie Antimony-124 source, if he is 760 cm from the source? (Weekly MPE = 300 mrem.)

8. At what distance from the source used in problem 7 would one place a sign and barricade in order to restrict unauthorized personnel from entering an area where the dose rate is greater than 5 mrad/hr?

9. A radiation worker performing an experiment requires the use of 500 mc of Antimony-125 fifty (50) times per week for 30 seconds each time. What is the minimum length remote handling tool he can use and not exceed a dosage of 300 mrem/week?

V. Solutions.

1. From decay scheme on page 388, Pam 25 -

$E_{\gamma 1} = 0.13632 \quad (99.8\%)$

$E_{\gamma 2} = 0.7064 \quad (0.18\%) \quad \text{Not used} < 3\%$

$S_\gamma = 0.56 \text{ n CE}$

$= (0.56)(0.998)(7)(0.13632)$

$= \underline{\underline{0.534 \text{ rhm}}}$

2. From column 5, page 254, Pam 25 -

$E_{\gamma 1} = 0.601 \quad (8\%)$

$E_{\gamma 2} = 0.630 \quad (27\%)$

$E_{\gamma 3} = 0.835 \quad (96\%)$

$E_{\gamma 4} = 0.894 \quad (10\%)$

$E_{\gamma 5} = 1.050 \quad (7\%)$

$E_{\gamma 6} = 1.465 \quad (3.5\%)$

$E_{\gamma 7} = 1.60 \quad (5\%)$

$E_{\gamma 8} = 1.860 \quad (5\%)$

$E_{\gamma 9} = 2.201 \quad (26\%)$

$E_{\gamma 10} = 2.50 \quad (20\%)$

$S_\gamma = 0.56 \text{ C } \Sigma nE$

$= (0.56)(120)[(0.08)(0.601) + (0.27)(0.63) + (0.96)(0.835) + (0.1)(0.894) + (0.07)(1.05) + (0.035)(1.465) + (0.05)(1.6) + (0.05)(1.86) + (0.26)(2.201) + (0.2)(2.5)]$

$= (67.2)(0.0481 + 0.17 + 0.802 + 0.0894 + 0.0735 + 0.0513 + 0.08 + 0.093 + 0.5723 + 0.5)$

$= (67.2)(2.4803)$

$= \underline{\underline{166.6 \text{ rhm}}}$

3. From column 5, page 256, Pam 25 -

$$E_{\gamma 1} = 0.511 \quad (59\%)$$

$$E_{\gamma 2} = 0.596 \quad (61\%)$$

$$E_{\gamma 3} = 0.635 \quad (14\%)$$

$$S_\gamma = 0.56\ C\ \Sigma nE$$

$$= (0.56)(420\ mc)[(0.59)(0.511) + (0.61)(0.596) + (0.14)(0.635)]$$

$$= (235.2)(0.3015 + 0.3636 + 0.0889)$$

$$= (235.2)(0.754)$$

$$= 177.3\ mrhm$$

$$R = \frac{S}{d^2} = \frac{177.3\ mrhm}{(0.25)^2} = \frac{177.3}{0.0625} = \underline{\underline{2840\ mrad/hr}}$$

4. From decay scheme on page 387, Pam 25 -

$$E_{\gamma 1} = 0.8469 \quad (53\%)$$

$$E_{\gamma 2} = 2.658 \quad (30\%)$$

$$E_{\gamma 3} = 2.957 \quad (15\%)$$

$$E_{\gamma 4} = 3.37 \quad (1.3\%) \quad \text{Not used, } < 3\%$$

$$S_\gamma = 0.56\ C\ \Sigma nE$$

$$= (0.56)(720\ mc)[(0.53)(0.8469) + (0.3)(2.658) + (0.16)(2.957)]$$

$$= (403.2)(0.449 + 0.797 + 0.473)$$

$$= (403.2)(1.719)$$

$$= 694\ mrhm$$

$$D = \frac{S}{d^2} \times t = \frac{694\ mrhm}{(2.3)^2}(7.5) = \frac{(694)(7.5)}{5.29} = \underline{\underline{984\ mrad}}$$

5. From decay scheme, page 395, Pam 25 -

$E_{\gamma 1} = 0.04 \quad (3\%)$

$E_{\gamma 2} = 0.298 \quad (1\%) \quad$ Not used < 3%

$E_{\gamma 3} = 0.36 \quad (1\%) \quad$ Not used < 3%

$E_{\gamma 4} = 0.537 \quad (89\%)$

$E_{\gamma 5} = 0.6505 \quad (7\%)$

$$S = Rd^2 = (270 \text{ mrad/hr})(3)^2 = (270)(9)$$

$$= 2430 \text{ mrhm or } 2.43 \text{ rhm}$$

$$C = \frac{S}{0.56 \, \Sigma \, nE}$$

$$= \frac{2.43 \text{ rhm}}{(0.56)[(0.03)(0.04) + (0.89)(0.537) + (0.07)(0.6505)]}$$

$$= \frac{2.43}{(0.56)(0.0012 + 0.478 + 0.0455)} = \frac{2.43}{(0.56)(0.5247)}$$

$$= \frac{2.43}{0.294} = \underline{\underline{8.27 \text{ curies}}}$$

6. From decay scheme, page 389, Pam 25 -

$E_{\gamma 1} = 1.3325 \quad (0.12\%) \quad$ Not used < 3%

$E_{\gamma 2} = 2.158 \quad (0.013\%) \quad$ Not used < 3%

$E_{\gamma 3} = 2.5057 \quad (99\%)$

$$S = 0.56 \text{ n CE} = (0.56)(0.99)(5)(2.5057)$$

$$= 6.95 \text{ rhm or } 6950 \text{ mrhm}$$

$$d = \sqrt{\frac{st}{D}} = \sqrt{\frac{(6950 \text{ mrhm})(40)}{300}} = \sqrt{936} = \underline{\underline{30.4 \text{ meters}}}$$

7. From column 5, page 292, Pam 25 -

$E_{\gamma 1}$ = 0.603 (97%)

$E'_{\gamma 2}$ = 0.644 (7%)

$E_{\gamma 3}$ = 0.72 (14%)

$E_{\gamma 4}$ = 0.967 (2.4%) Not used < 3%

$E_{\gamma 5}$ = 1.048 (2.4%) Not used < 3%

$E_{\gamma 6}$ = 1.31 (3%)

$E_{\gamma 7}$ = 1.37 (5%)

$E_{\gamma 8}$ = 1.45 (2%) Not used < 3%

$E_{\gamma 9}$ = 1.692 (50%)

$E_{\gamma 10}$ = 2.088 (7%)

$$S_\gamma = 0.56\ C\ \Sigma nE$$

$$= (0.56)(10)[(0.97)(0.603) + (0.07)(0.644) + (0.14)(0.72) + (0.03)(1.31) + (0.05)(1.37) + (0.5)(1.692) + (0.07)(2.088)]$$

$$= (5.6)(0.585 + 0.0451 + 0.1001 + 0.0393 + 0.0685 + 0.846 + 0.1463)$$

$$= (5.6)(1.8303)$$

$$= 10.24 \text{ rhm}$$

$$t = \frac{Dd^2}{S} = \frac{(0.3)(7.6)^2}{10.24} = \underline{\underline{1.69 \text{ hours}}} \text{ or 1 hour and 41 minutes}$$

8. $$d = \sqrt{\frac{S}{R}} = \sqrt{\frac{10{,}240 \text{ mrhm}}{5 \text{ mrad/hr}}} = \sqrt{2048} = \underline{\underline{45.3 \text{ meters}}}$$

9. From column 5, page 292, Pam 25 -

$$E_{\gamma 1} = 0.176 \quad (6\%)$$

$$E_{\gamma 2} = 0.427 \quad (31\%)$$

$$E_{\gamma 3} = 0.463 \quad (10\%)$$

$$E_{\gamma 4} = 0.599 \quad (24\%)$$

$$E_{\gamma 5} = 0.634 \quad (11\%)$$

$$E_{\gamma 6} = 0.66 \quad (3\%)$$

$$S_{\gamma} = 0.56\ C\ \Sigma nE$$

$$= (0.56)(500\ \text{mc})[(0.06)(0.176) + (0.31)(0.427) + (0.1)(0.463) + (0.24)(0.599) + (0.11)(0.634) + (0.03)(0.66)]$$

$$= (280)(0.0107 + 0.128 + 0.0463 + 0.1438 + 0.0697 + 0.0218)$$

$$= (280)(0.4203)$$

$$= 118\ \text{mrhm}$$

$$t = (50)(30) = 1500\ \text{sec} = 0.417\ \text{hours}$$

$$d = \sqrt{\frac{st}{D}} = \sqrt{\frac{(118)(0.417)}{300}} = \sqrt{0.164} = \underline{\underline{0.405\ \text{meters or}\ 40.5\ \text{cm}}}$$

INTRODUCTION TO SCALER COUNTING

DF200, INTRODUCTION TO SCALER COUNTING

I. Reference and Discussion.

A. Reference: ST 3-155, ch 12.

B. Discussion.

1. General.

The scaler is a laboratory radiac instrument designed to yield precise data on the activity of a radioactive sample. It measures gamma and beta radiation, and under certain conditions will measure alpha radiation. Due to its precision, this instrument, when used with the proper auxiliary equipment, can be used to:

a. Determine the energy of gamma emissions.

b. Determine the half-life of an isotope.

c. Determine the energy of gamma emissions.

d. Determine the energy of beta emissions.

e. Determine the energy of alpha emissions.

f. Compare the counting rates of two samples.

g. Determine the decay constant for mixed fission products.

Such information is needed by the Health Physics and Radiation Safety Officers, and may be required by commanders in the event of nuclear warfare.

2. Description.

a. A scaler has three basic components. They are:

(1) A sensitive radiation detecting unit.

(2) A recording unit.

(3) A precise timing unit.

b. Figure 1 is an illustration of a typical scaler and its component parts.

c. The detecting unit of the scaler can be:

(1) A Geiger-Mueller tube.

(2) A scintillation crystal.

(3) A gas proportional tube or "counter."

It is usually shielded with lead to reduce background radiation. When the detecting unit is a Geiger-Mueller tube, it is mounted in a fixed position inside a lead pig. Sample holders are located below the GM tube in such manner that sample orientation can be reproduced.

The recording unit takes the signals (discharge from GM tube, flash from scintillation crystal or discharge from the proportional tube) from the detecting unit and records them. The recording device is generally a combination of electronic and mechanical registers, although electronic registers are often used alone.

The timing unit is a precise time measuring device. It is designed to record time, usually in minutes and hundredths of minutes, during the time of measurement. It may or may not be set to stop the recording device after a pre-set time, or alternately, the recording device may or may not be set to stop the timing device after a pre-set number of counts has been registered.

The components of the scaler may detect and count gamma, alpha, and beta radiations from a sample in total count. The counting rate, counts per unit time, is found by dividing the total count by the total time, usually minutes to find counts per minute. Most scalers register with greatest efficiency when the counting rate does not exceed 5,000 counts per minute. A special unit or tube is required for alpha counting.

3. Operation.

Effective use of the scaler to determine any of the items mentioned above requires:

a. Careful sample preparation.

b. Determination of efficiency of detecting unit.

Careful consideration must be given to the chemical and physical form in which the samples are to be measured. This is necessary to minimize errors due to back- and self-scattering and self-absorption. However, a detailed discussion of the experimental techniques involved are beyond the scope of this manual.

Since the detecting element will only "count" events that occur within it, the counting rate will not be the disintegration rate of the sample. The disintegration rate of the sample is the number of nuclear disintegrations which take place in the sample in a unit time, i.e., disintegrations per minute or per second. The counting rate is actually the number of nuclear disintegrations which are DETECTED in a unit time. Thus, the counting rate will differ from the disintegration rate by the number of nuclear disintegrations which are not detected by the detecting element.

4. Geiger-Mueller Tube.

With a GM tube this ratio between counting rate and disintegration rate is known as the tube's efficiency. This efficiency is the result of three factors. These factors are:

a. Resolving time of the GM tube.

b. Geometry of the tube and sample.

c. Energy sensitivity of the GM tube.

The resolving or dead time of a GM tube is the time following a primary ionizing event during which the tube is insensitive to ionizing radiations. The dead time of an average Geiger-Mueller tube is 0.0002 second (200 u sec). During this 0.0002 seconds, if another primary ionizing event takes place in the tube it will not cause a discharge of the Geiger-Mueller tube, and, therefore, will not be counted. A GM tube having a 0.0002 second dead time will record all of 5,000 evenly spaced ionizing events per second occurring within it. However, should 6,000 evenly spaced ionizing events per second occur, 1,000 events would not be counted. The problem increases when one considers that a radioactive material does not decay at a perfectly constant rate but decays randomly in fits and spurts, although the sample does have an average decay rate.

A pictorial view of this dead time and randomness of disintegrations is presented in figure 2. Here the unevenly spaced arrows indicate random disintegrations and the blocks represent the resolving or dead time of a GM tube. When the disintegration causes ionizing events while the tube is completely charged as in A, B, D, and F, the events are recorded. When, however, the ionizing events occur during dead time as in C and E, counts will be lost. For example, one count is lost in C and two in E.

Hence, the higher the counting-rate the larger the fraction of counts that will be lost. It is possible to make corrections for the lost counts if the dead time is known. This can be determined rather easily. Knowing the dead time, a calibration curve can be constructed which will relate the observed counting rate to the true counting rate.

5. Resolving Time Determination.

The resolving time of the tube is measured by taking a series of three counts using two different sources. Counts are taken on the individual samples, plus a count of the two samples together. The total counts for the combination of the sources is greater than either single sample above, but less than the sum of the two samples. The reason for this lowered count is due to the radiation entering the tube during the dead time of the tube, or several radiations entering the tube simultaneously. The two samples chosen should be gamma emitters with a counting rate of about 5,000 counts per minute each.

The resolving time of the tube may be calculated by means of the following formula:

$$\text{Resolving time } (\tau) = \frac{R_1 + R_2 - R_{1,2} - R_b}{R_{1,2}^2 - R_1^2 - R_2^2}$$

where R_1 = cpm for sample No. 1.

R_2 = cpm for sample No. 2.

$R_{1,2}$ = cpm for the combination of samples 1 and 2.

R_b = cpm background.

Once the dead time is determined for a particular Geiger-Mueller tube a calibration curve can be constructed. The curve will relate the observed counting rate to the counts to be added to obtain the incident counting rate of the sample. This curve can be constructed by the use of the following equations:

$$\Delta R = R - R_o$$

where ΔR is the correction factor in cpm to be added to the observed counting rate.

R is the incident counting rate.

R_o is the observed counting rate.

then $R_o\tau$ = time/minute that the scaler is not counting.

τ is the dead time of the Geiger-Mueller tube.

$R \cdot R_o\tau$ = total number of counts missed.

$R - R_o$ = total number of counts missed.

then $R R_o\tau = R - R_o$

rearranging gives: $R = \dfrac{R_o}{1 - R_o\tau}$

substituting for R in the original equation the following is obtained:

$$\Delta R = \frac{R_o}{1 - R_o\tau} - R_o$$

rearranging gives the equation:

$$\Delta R = \frac{R_o^2\tau}{1 - R_o\tau}$$

where R_o is observed counting rate

ΔR is cpm to be added to the observed counting rate to give the incident counting rate.

A graph of "observed counts" versus "counts per minute to be added, ΔR" can be constructed on log-log paper. In order to obtain points for the curve "observed counts versus counts to be added," a value for ΔR is obtained by solving the above equation in which the resolving time of the GM tube used is substituted for τ and by assigning an arbitrary value to R_o. This arbitrary value of R_o and the resulting value of ΔR when plotted on log coordinates will establish one point of the desired curve. At least four additional points should be established by assigning other arbitrary values to R_o and solving for the corresponding ΔR. These points will plot essentially as a straight line. When such a curve is employed, Incident Count (R) may be obtained by adding to any given value of R_o the value of ΔR corresponding to R_o read from the graph. A graphical solution saves considerable time when numerous readings are to be corrected.

6. Geometry and Energy Sensitivity.

Geometry of the tube and sample is defined as the ratio of the total disintegration being emitted and the number of disintegrations actually counted by the scaler. This ratio is generally expressed as a percentage. If for a certain physical set-up of the detecting element and sample in the lead pig, 10% of the total disintegrations of a sample were counted in a unit time, then the "geometry" is said to be 10%. The remaining 90% of the disintegrations go off in other directions and are not counted. In order to obtain accurate data that is meaningful, the "geometry" must always be the same and must not change. Figure 3 illustrates two extremes of geometry.

Energy sensitivity of a GM tube is a function of the energy of radiation and the amount of absorbing material between the atom that disintegrates and the gas of the GM tube. A typical plot of percent efficiency versus energy is shown in Figure 4. For low energy beta radiation, lower efficiency is due to self absorption within the sample, absorption in the material and the air between the sample and wall of the GM tube and absorption in the wall of the GM tube. A similar graph would be obtained for gamma radiation.

Therefore, to determine any of the items mentioned above it is necessary that the samples to be counted always be placed in the same position with respect to the GM tube. That is, the sources must be the same distance from, and in the same relative position with respect to the GM tube.

This requirement for maintaining a constant geometry necessitates a permanent type sample holding device in order to assure a reproducible position. Such a device is shown in Figure 5.

7. Scintillation Counters.

The most common type of detector for measuring gross counting rates is the scintillation well counter. It consists of a crystal, usually sodium iodide activated with thallium, in which a small hole is bored to permit entry of a sample vial. The sodium iodide crystal is connected to the front of a photomultiplier tube by a light pipe and the crystal and tube are surrounded by an aluminum housing. The detector unit (the crystal and photomultiplier tube in the aluminum housing) is equipped with some type of lead shielding.

The scintillation detector is preferred for counting gamma radiation because solid sodium iodide is more efficient in attenuating gamma radiation than is the gas filled GM or proportional counter tube. When gamma radiation interacts with the sodium iodide crystal, some of the gamma radiation will interact by one of three possible processes. These are:

a. Photoelectric.

b. Compton interaction.

c. Pair production.

In each of the above processes, energetic electrons are ejected from an atom. This electron loses its energy either by ionization or excitation of the atoms through which it is passing. When the sodium iodide atoms are excited, they re-emit this excitation energy in the form of light photons. The number of photons produced is proportional to the energy of the particle producing the excitation.

The photomultiplier tube contains a photo cathode, usually made of silver-magnesium or cesium-antimony. When the light photons strike the photo cathode, "photoelectrons" of 1 to 2 ev energy are ejected approximately 10 to 15% of the time. These photo electrons form a photo electric current which is amplified by passage along a series of dynodes. Dynodes are electrodes so arranged that the electrons from each preceding dynode are focused on the next dynode. Each dynode in the series is at a higher potential (approximately 150 volts in most cases) than that of the preceding dynode. This causes production of secondary electrons at the next dynode surface. The photoelectrons in passing through the dynode series are joined by more and more secondary electrons, which results in an amplified current.

Since the number of light photons produced is dependent on the energy of the photoelectric, Compton or pair production electron, which in turn is dependent on the energy of the gamma radiation, the scintillation detector responds differently to gamma radiation of different energy.

8. Background Corrections.

Regardless of the detecting unit used with the scaler, correction must be made for the count due to background radiation. Background radiation is radiation arising from cosmic rays and stray radiations from other sources.

The total recorded counts are actually from two sources; the first is the sample itself, and the second is background radiation. That is:

$$R_{total} = R_{sample} + R_{background}$$

where

R_{total} is the observed counting rate

R_{sample} is the counting rate of the sample,

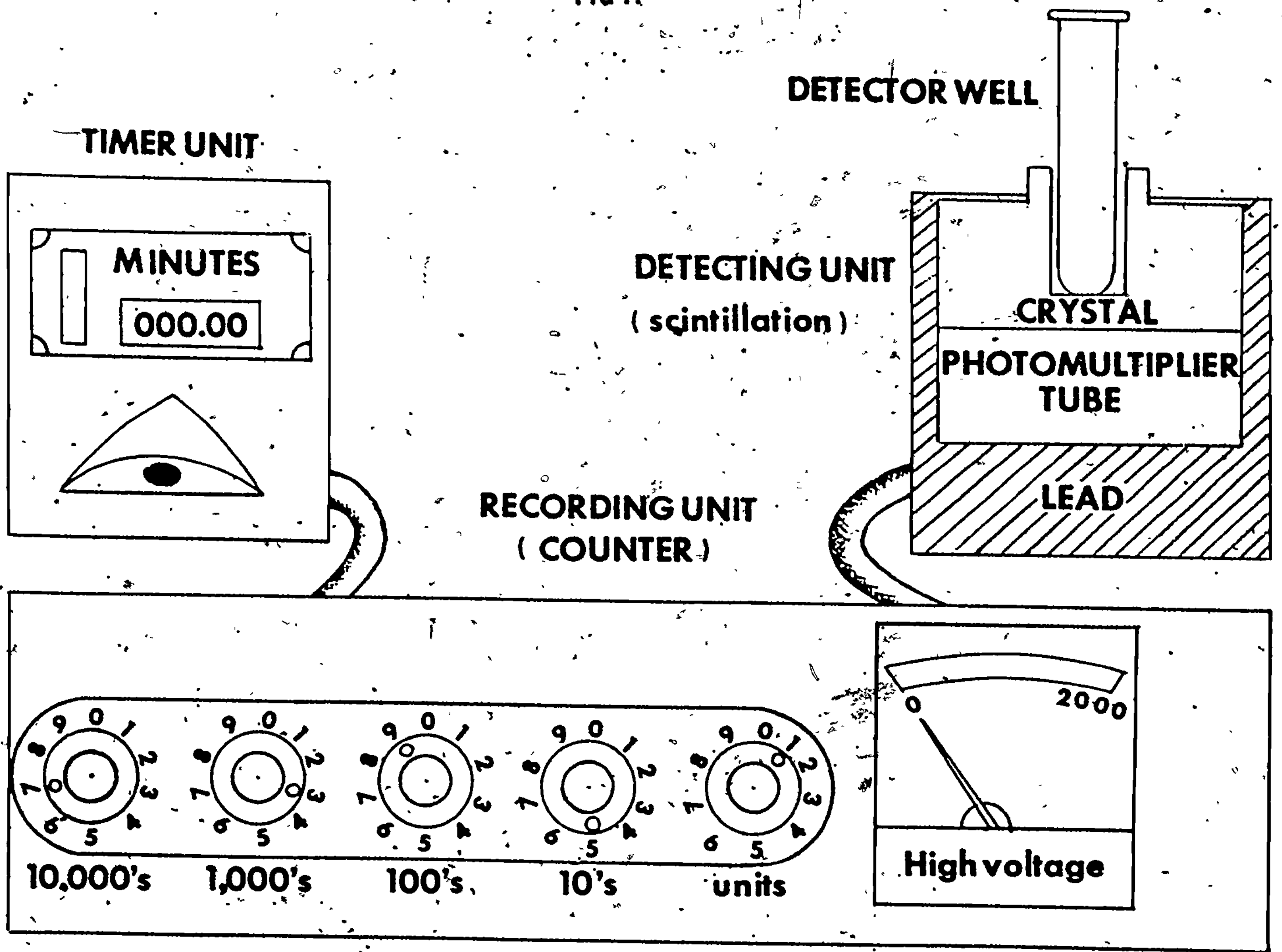
and $R_{background}$ is the counting rate of the background radiations.

The background counting rate is determined by counting with the detecting unit empty. The specific method used for correction depends on the detecting unit used, but in general to determine the true count of any sample the background count is subtracted from the total count.

Random Fluctuation Error. The decay of an individual atom in the source being counted is a matter which is totally unpredictable. It may be said that the decay of an atom occurs at random. In spite of the individual randomness of the decay process in the source, the number of decays observed from a source consisting of a large number of atoms tends to conform to a certain expected value. This tendency to approach an expected value becomes count as an estimate of the expected count.

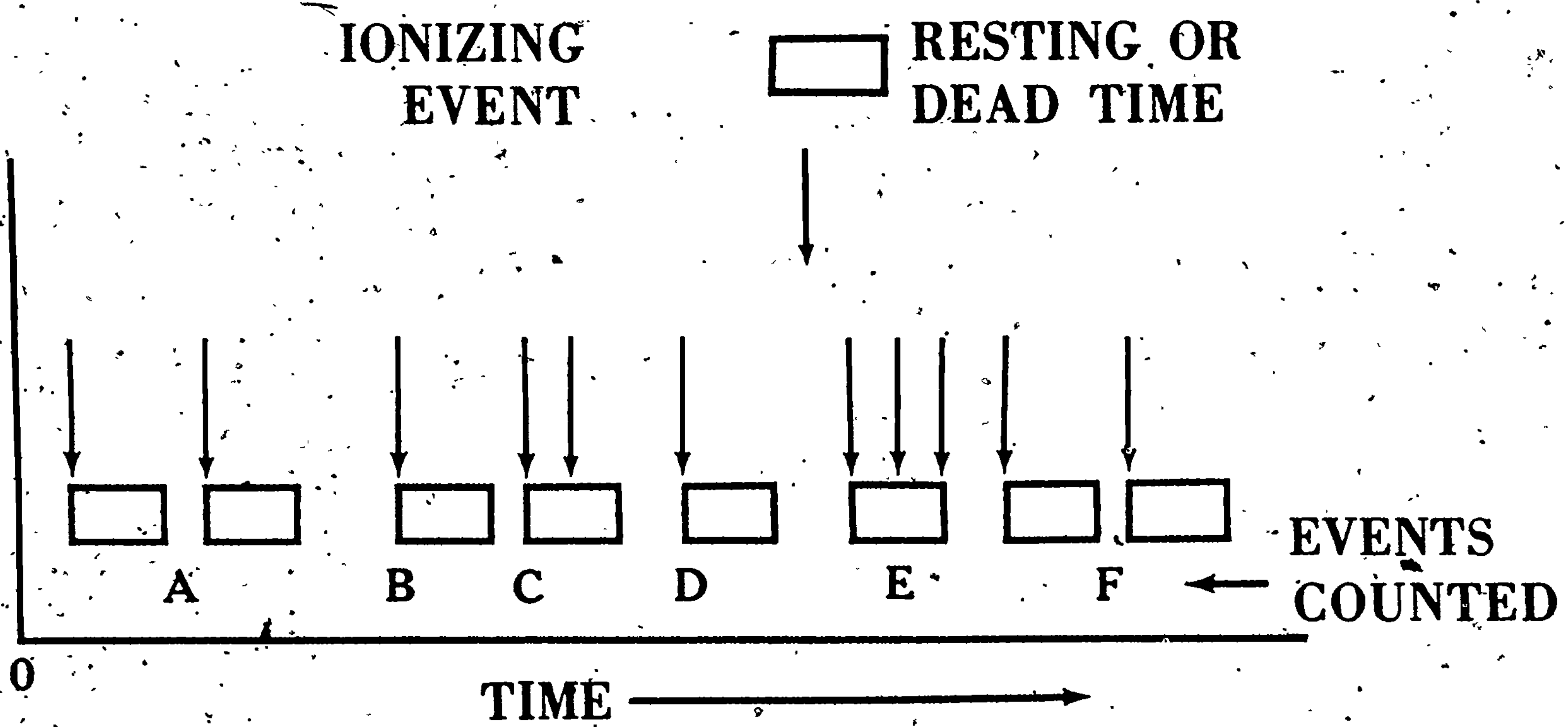
This random fluctuation of the observed count about the expected count introduces an error into scaler counting results. The error is inherent in the nature of radioactive decay and in non-preventable. Since the amount of the deviation of observed count from expected count is not predictable, it is impossible to introduce a correction for the error. The only recourse is to count a sufficient number of decays so that the effect of the random fluctuations is reduced to negligibility, the observed count then approximating closely the expected count. However, in practice this is seldom feasible, but after a number of counts have been made we can calculate the probable error. This can be done by use of the graph on page 118 of Pam 25. Instructions for use of the graph are contained in Pam 25.

FIG 1.



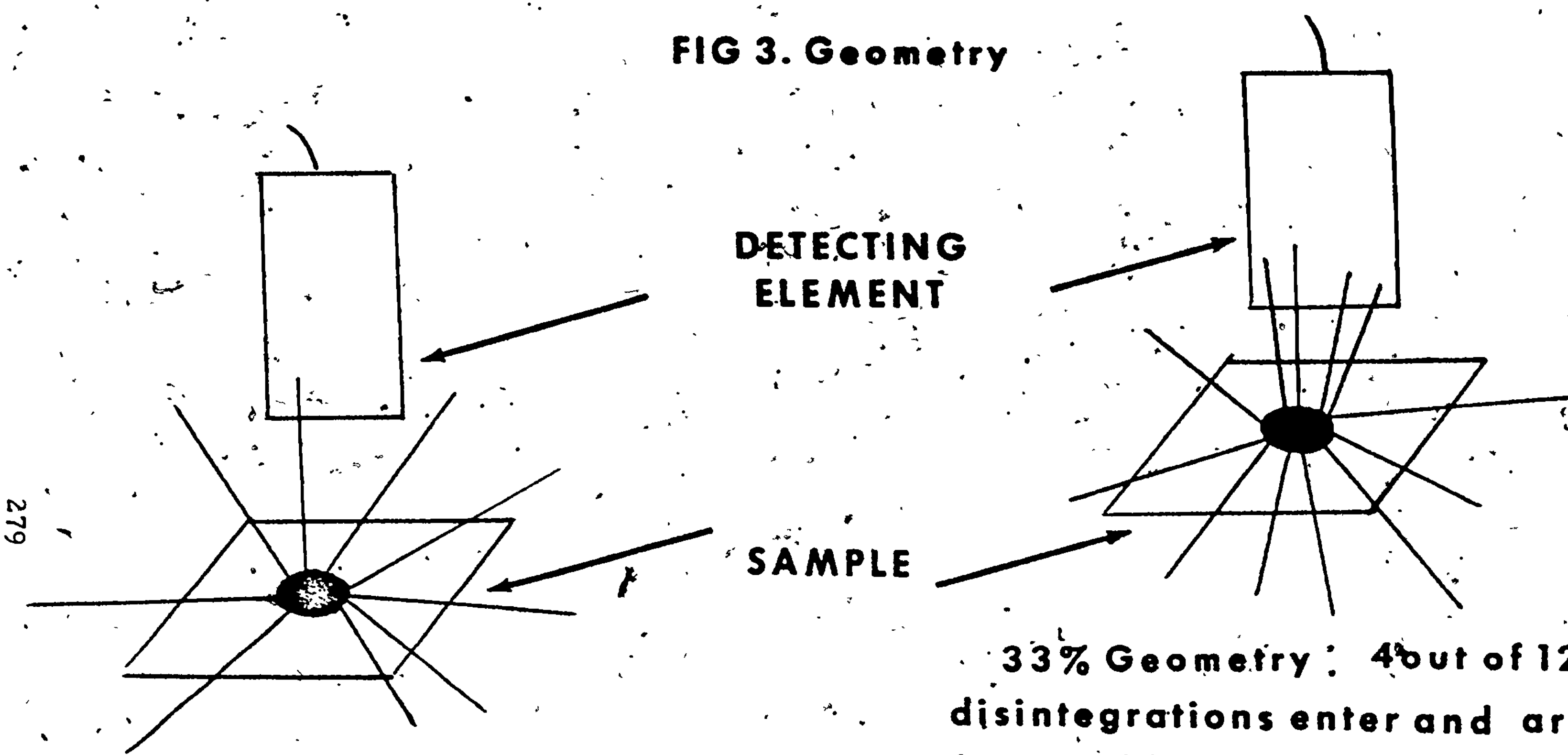
Scaler Assembly

FIG2.



DEAD TIME SCHEMATIC

FIG 3. Geometry



10% Geometry : 1 out of 10 disintegrations enter and are detected by the detecting element

33% Geometry : 4 out of 12 disintegrations enter and are detected by the detecting element

By placing the source closer to the detecting unit, the geometry of the system is increased and hence the efficiency of detecting unit.

FIG 4. β^- Energy efficiency of a GM tube

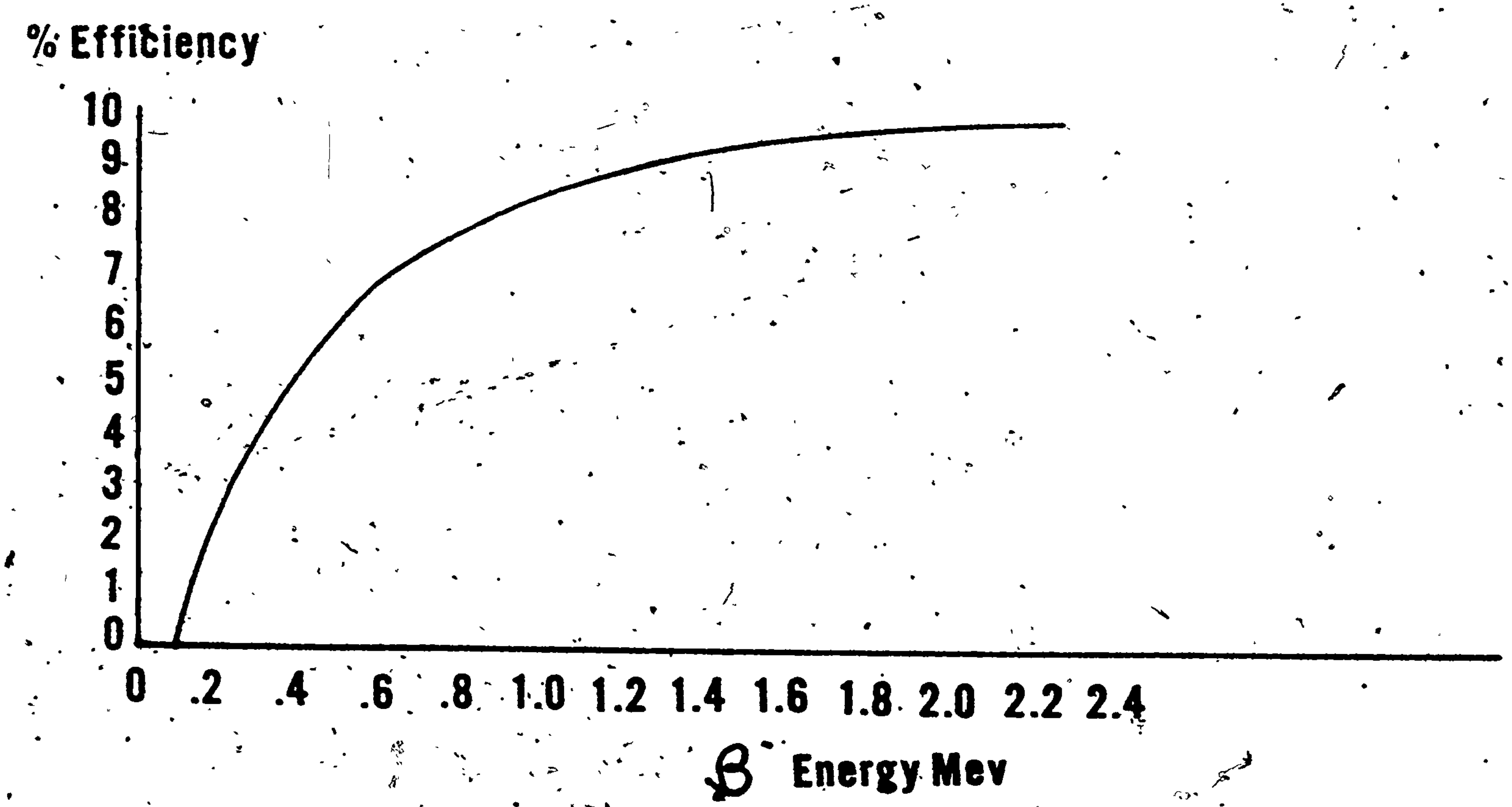
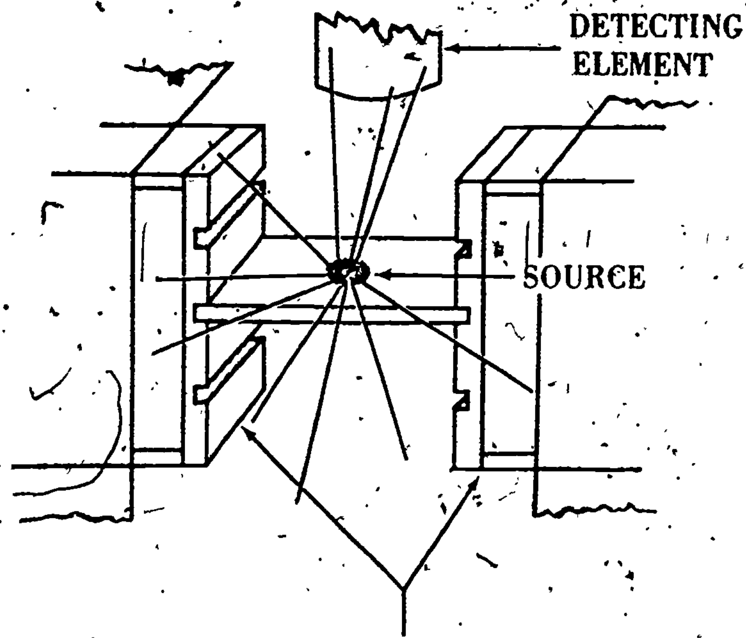
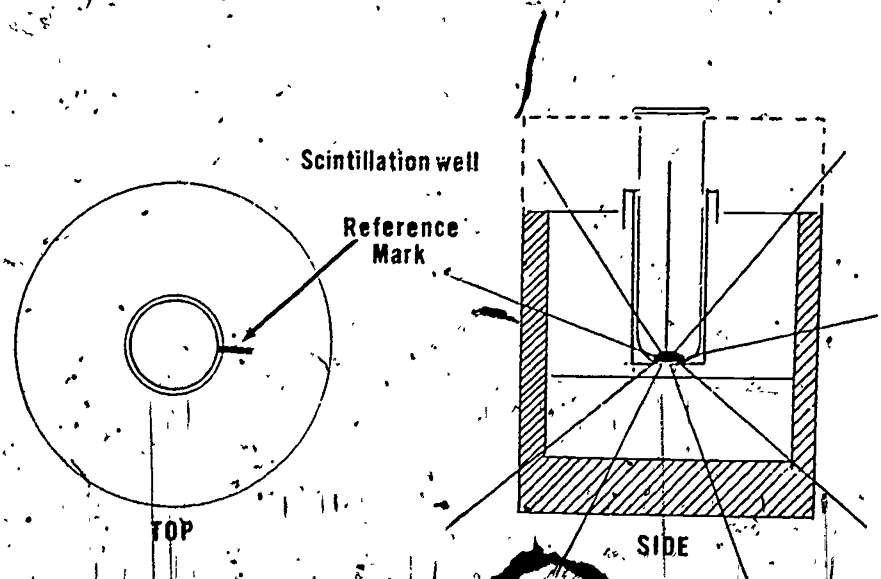


FIG 5.

SAMPLE HOLDING DEVICES



a. All the equipment shown above will be contained in a lead pig so as to reduce the background radiation. The sample holding device may consist of lucite blocks with grooves in which samples can be slid in and out.



b. The well assembly gives close to 100% geometry. Reproducibility is obtained by marking the sample holder and opening

II. Lesson Objectives and Notes:

A. Scaler counters, their use and capabilities

B. Operating voltage and resolving time determination.

STUDENT NO. ____________________

CLASS ____________________

DATE ____________________

INSTRUCTOR ____________________

LABORATORY EXERCISE

SCALERS

OPERATING VOLTAGE AND RESOLVING TIME OF A GM TUBE

III. Laboratory Exercise.

A. Determination of Operating Voltage.

1. Check to be sure the cord from the GM tube in the lead pig is plugged into the receptacle marked "GM" at the rear of the scaler.
2. Make sure all switches are OFF.
3. Make sure the line cord from the scaler is plugged in.
4. Turn power switch ON.
5. Make sure the high voltage control is fully counterclockwise.
6. Turn high voltage power switch ON (voltmeter should register about 300 volts).
7. Depress reset switch until all glow tubes register "zero."
8. Turn count switch into the UP position.
9. If timer is not operating, depress the switch on the timer.
10. Open the door of the lead pig and place the radioactive source in one of the grooves (usually second from the top).
11. Rotate the high voltage control slowly and stop when the right-hand glow tube first starts to register counts. Decrease the voltage 50 volts. This is the starting potential.
12. Depress the count switch and zero the timer.
13. Turn the count switch up and take a 2-minute count, turning timer and scaler off with the count switch.
14. Record the number of counts and the voltage on the data sheet.
15. Increase high voltage by 50 volts and take a 2-minute count.
16. Record voltage and counts per minute.
17. Zero decade tubes and timer.
18. Repeat steps 15 through 17 until a 500 count per minute increase over the previous count is recorded OR until a voltage specified by the instructor is reached. DO NOT EXCEED this voltage.

19. Turn high voltage control knob fully counterclockwise.

20. Turn high voltage OFF.

21. Turn power OFF.

22. Remove radioactive source from lead pig.

PROCESSING DATA

Plot counts per minute VS voltage on linear graph paper (will be furnished by the instructor) and draw a smooth line through the points. The resulting curve will be characteristic for the GM tube used. The operating voltage can now be selected on the flat portion of the curve, one-third of the distance from plateau beginning to onset of continuous discharge.

B. Data.

INSTRUMENT MAKE ______________ MODEL ___________ SCALER NO. ________

DATA FOR PLOTTING GM PLATEAU

VOLTAGE	TOTAL COUNTS	TOTAL TIME	CPM

Operating Voltage ________________ volts.

C. Determination of Resolving Time.

Data for the resolving time determination will be obtained as outlined in paragraph 12.8 of ST 3-155.

1. Obtain a handling tool and two (2) radiation sources from the instructor. The sources are on a double-holed plastic planchet holder.

2. Remove the left source with the handling tool and place it on a piece of paper on the lab bench. Place the right source and planchet on the third shelf in the lead pig with the planchet to the right rear and count. This is the value for R_1.*

3. Carefully remove the source holder from the scaler counter and place the second source on the holder (left side) with the first source. Replace the holder into the scaler in the identical position as before and count the combined sources. This is the $R_{1,2}$ value. *

4. Remove the right source and count the left source by itself. This is the R_2 value.*

5. Remove the planchet and run a background count.*

6. Calculate the resolving time of the GM tube.

* Count for 5 minutes on all readings. Record your data in Table I.

TABLE I

Sample	Total Count	cpm
1		R_1 =
1,2		$R_{1,2}$ =
2		R_2 =
Background		R_b =

$$\tau = \frac{R_1 + R_2 - R_{1,2} - R_b}{R_{1,2}^2 - R_1^2 - R_2^2} \qquad (1)$$

CALCULATIONS:

D. Graph Construction.

A graph of observed counts per minute (R_o) versus counts per minute to be added (ΔR) can be constructed on log-log graph paper. When the constructed curve (straight line) is employed, the true counting rate (R) may be obtained by adding to any given value of R_o the value of ΔR corresponding to R_o read from the graph.

From the equation $R - R_o = \Delta R$

where: ΔR = The correction factor in cpm to be added to the observed counting rate.

R = The true counting rate, cpm.

R_o = The observed counting rate, cpm,

then:

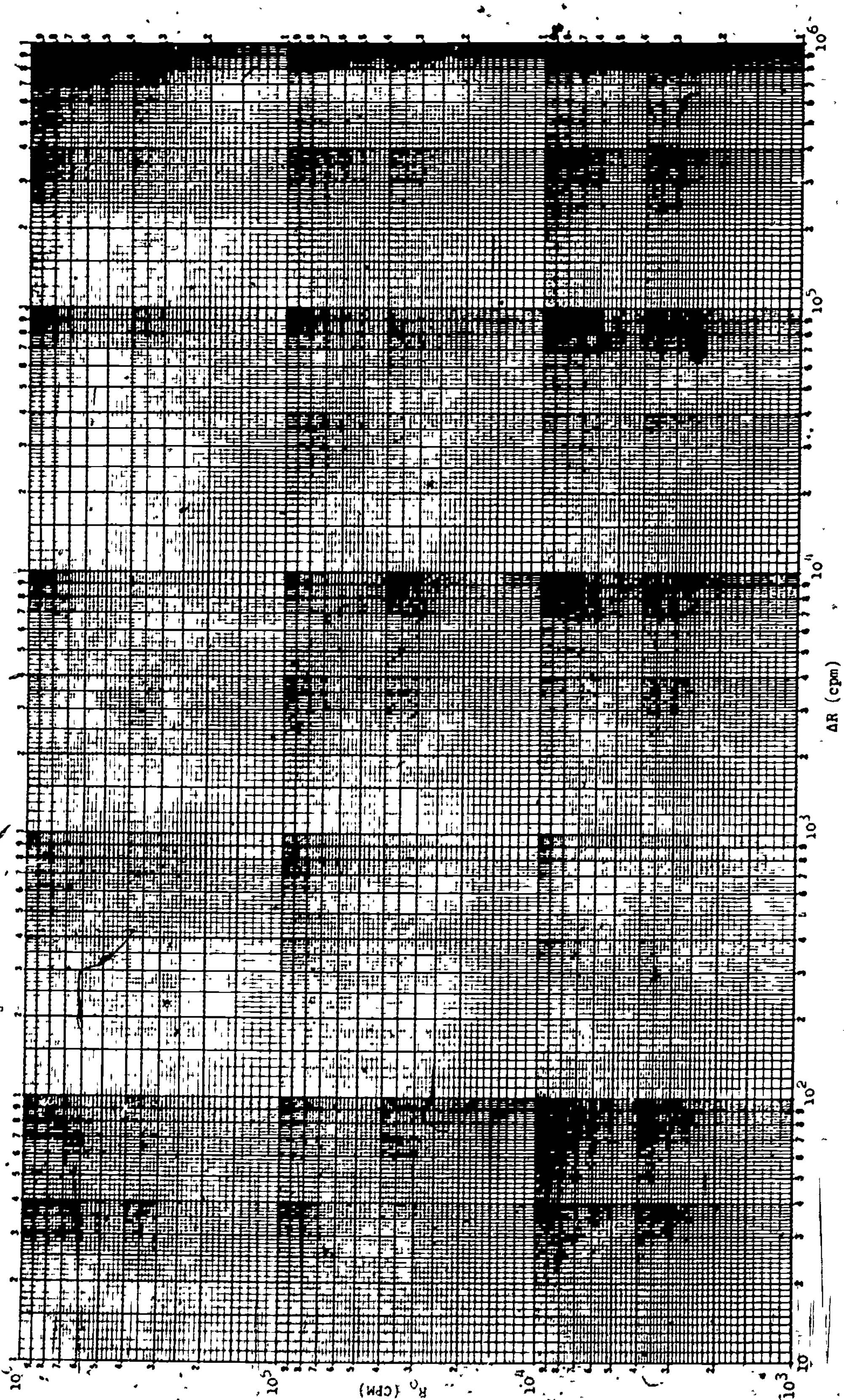
$$\Delta R = \frac{R_o^2 \tau}{1 - R_o \tau} \quad (2)$$

(See para 12.8, ST 3-155)

Use the values of τ obtained in C above and complete Table II by substituting the listed values of R_o in equation 2 above and solving for the corresponding ΔR. Plot the R_o and ΔR pairs on the log-log graph provided; the observed count (R'_o) is plotted on the vertical axis and the counts to be added to R (ΔR) on the horizontal axis.

TABLE II

R_o (cpm)	ΔR (cpm)
5,000	
10,000	
33,000	
50,000	


ΔR (cpm)
R_0 (CPM)

IV. Problems - Introduction to Scaler Counting.

1. To determine the resolving time of a particular GM tube, the following data were obtained:

R_1 = 8,500 cpm $R_{1,2}$ = 13,420 cpm

R_2 = 7,000 cpm R_b = 40 cpm

a. Calculate the resolving time of the tube.

b. The observed count (negligible background) of a particular sample using this tube was 500 cpm. What would be the true count?

c. Another sample gave an observed count (negligible background) of 20,000 cpm. Calculate ΔR (counts to be added to the observed count to obtain the true count) for this observed count.

d. Calculate the maximum counting rate in cpm of this GM tube.

2. A known source has a disintegration rate of 5,000 dpm. When counted on a scaler the observed count was 750 cpm. What was the efficiency of the scaler counter?

3. An unknown source counted on a scaler counter had an observed counting rate of 7,400 cpm. The overall efficiency of the scaler was 10%.

a. What is the disintegration rate of the sample?

b. What was the activity in microcuries of the above sample?

4. A certain scaler had a resolving time of 1×10^{-6} min/count. An observed counting rate of 100,000 cpm was obtained on this scaler. 90% of the total disintegrations of the sample were lost due to geometry and sensitivity errors. How many microcuries are present in the sample counted?

V. Solutions to Problems.

1. a. $$\tau = \frac{R_1 + R_2 - R_{1,2} - R_b}{R_{1,2}^2 - R_1^2 - R_2^2}$$

$$= \frac{8500 + 7000 - 13420 - 40}{1.80(10)^8 - 0.723(10)^8 - 0.49\ (10)^8}$$

$$= \frac{2040}{0.587\ (10)^8}$$

$$= \frac{2.040(10)^3}{0.587\ (10)^8}$$

$$= 3.47\ (10)^{-5}\ \underline{\text{min/count}}$$

b. $$R = \frac{R_o}{1 - R_o \tau}$$

$$R = \frac{500}{1 - (500)(3.47 \times 10^{-5})}$$

$$R = \frac{500}{1 - 1.74\ (10)^{-2}}$$

$$R = \frac{500}{1 - 0.0174}$$

$$R = \frac{500}{0.983}$$

$$R = \underline{509\ \text{cpm}}$$

c. $\Delta R = \dfrac{R_o^2 \tau}{1 - R_o \tau}$

$\Delta R = \dfrac{(3.47 \times 10^{-5})(2.0 \times 10^4)^2}{1 - (3.47 \times 10^{-5})(2.0 \times 10^4)}$

$\Delta R = \dfrac{1.388 \times 10^4}{1 - 6.94 (10)^{-1}}$

$\Delta R = \dfrac{1.388 (10)^4}{0.306}$

$\Delta R = \underline{4.55 \times 10^4 \text{ cpm}}$

d. $R_{max} \tau = 1$

$R_{max} = \dfrac{1}{\tau}$

$R_{max} = \dfrac{1}{3.47 (10)^{-5}}$

$R_{max} = \underline{2.88 (10)^4 \text{ cpm}}$

2. $\text{Eff} = \dfrac{\text{observed count rate}}{\text{disintegration rate}}$

$= \dfrac{750}{5000}$

$= \underline{0.15 \text{ or } 15\%}$

3. a. $\text{Eff} = \frac{R_o}{\text{dpm}}$

$$\text{dpm} = \frac{R_o}{\text{Eff}}$$

$$\text{dpm} = \frac{7400}{0.1}$$

$$\text{dpm} = \underline{7.4 \times 10^4}$$

b. $(7.4 \times 10^4 \text{ dpm}) \left(\frac{1 \text{ min}}{60 \text{ sec}}\right) \left(\frac{1 \mu\text{Ci}}{3.7 \times 10^4 \text{ dps}}\right) = \underline{3.33 \times 10^{-2} \mu\text{Ci}}$

4. Resolving time correction.

$$\Delta R = \frac{R_o^{\,2}\, \tau}{1 - R_o \tau}$$

$$= \frac{(10^5)^2\,(10^{-6})}{1 - 10^5(10^{-6})}$$

$$= \frac{10^4}{0.9}$$

$$= \underline{1.11 \times 10^4} \text{ counts lost}$$

Counts corrected for resolving time.

$$R' = R_o + \Delta R$$

$$= 100,000 + 11,100$$

$$R = 111,100$$

Geometry and energy correction.

$$\text{dpm} = \frac{111,100}{0.1}$$

$$= 1,111,000 \text{ dpm}$$

$$= 1.111 \times 10^6 \text{ dpm}$$

$$1.111 \times 10^6 \frac{\text{dis}}{\text{min}} \left(\frac{1 \text{ min}}{60 \text{ sec}}\right) \left(\frac{1 \mu\text{Ci}}{3.7 \times 10^4 \frac{\text{dis}}{\text{sec}}}\right) = 0.501 \mu\text{Ci}$$

NEUTRONS

DF212

DF212, CHARACTERISTICS AND DETECTION OF NEUTRONS

I. References and Discussion.

A. References: DA Pam 39-3, para [illegible] 67, 8.93-8.97, 9.11, 9.31-9.39; ST 3-155, para 4.4, ch 11.

B. Discussion:

1. General.

Neutrons have properties which make them important in contemporary science and technology. Because they are uncharged heavy particles, neutrons induce many nuclear reactions which are a valuable source of information about the nucleus. The most striking use of neutrons is in the chain reaction involving fissile materials in nuclear reactors and in weaponry.

There are no radioisotopes of practical significance which emit neutrons directly, except during the fissioning of certain heavy element isotopes. Neutrons can be produced indirectly, however, by a number of nuclear processes involving charged particles or energetic gamma photons as projectiles.

The absorption of an alpha particle by the nucleus of beryllium-9 with the subsequent emission of a neutron is one example, and may be written as follows:

$$^{9}Be + {}^{4}He \rightarrow {}^{1}n + {}^{12}C + 5.70 \text{ Mev}$$

or $^{9}Be\ (\alpha\ ,\ n)\ {}^{12}C$

Although a small part of the 5.70 Mev energy is imparted to the product nuclei in recoil, most of the energy is imparted to the emitted neutron.

2. Classification of Neutrons.

Neutron energy is an important factor in the interactions of neutrons with matter. We therefore classify neutrons according to their energies. The terms "thermal," "epithermal (slow and intermediate), and "fast" each represent a broad, rather indefinite range of energies. These energy ranges are:

a. Thermal neutrons (up to 0.025 ev). Thermal neutrons are in thermal equilibrium with their environment at standard temperature and pressure.

b. Slow neutrons (0.025 ev to 100 ev). Slow neutrons are at the lower end of the epithermal range.

c. Intermediate neutrons (100 ev to 100 kev). Intermediate neutrons complete the epithermal range and are the most difficult to detect.

d. Fast neutrons (greater than 100 kev).

3. INTERACTION OF NEUTRONS WITH MATTER.

For neutrons to interact with matter, they must either enter the nucleus or come sufficiently close to it for the nuclear forces to interact. The reaction of a neutron with a nucleus $^{A}_{Z}X$ can be represented as

$$^{1}_{0}n + {}^{A}_{Z}X \rightarrow ({}^{A+1}_{Z}X)^{*}$$

where $({}^{A+1}_{Z}X)$ represents the compound nucleus in an excited state. The excess energy of the compound nucleus may be removed by the emission of one or more particles.

Processes in which neutrons are emitted are referred to as scattering processes. The scattering is inelastic or elastic, depending on whether the nucleus is left in an excited state (nonconservation of energy) or in an unexcited state (conservation of energy). In either case, the neutron energy is degraded, the amount of degradation being larger for inelastic scattering.

Processes in which neutrons are absorbed and a different particle or photon is emitted are referred to as absorption.

The various mechanisms by which neutrons interact with matter are:

a. Elastic scattering, (n, n). In elastic scattering the initial kinetic energy of the neutron is shared with the target nucleus. The nucleus recoils and is not left in an excited state. Energy is conserved in this interaction. The smaller the mass of the nucleus, the greater the fraction of the kinetic energy absorbed by the nucleus. Therefore, light nuclei are better for slowing down fast neutrons.

b. Inelastic scattering, (n, n), (n, nγ) or (n, 2n). This process is energetically possible only for fast neutrons. The nucleus is left in an excited state and energy is not conserved by the interaction. However, the subsequent loss of this excess energy of the nucleus will satisfy the law of conservation of energy.

c. Radiative capture, (n,γ). This absorption reaction is probably the most common of all reactions, since thermal neutrons induce this reaction in nearly all nuclides. Radiative capture <u>also</u> occurs with a very high probability for a number of nuclides in the epithermal range. This phenomenon is known as resonance capture. The gamma photons emitted in the (n,γ) reaction usually have energies of several Mev.

d. Absorption with charged particle emission, (n, p), (n,d), (n,α) etc. This type of reaction is most probable for light nuclides and fast neutrons since the charged particles must overcome the Coulomb barrier before escaping the nucleus. Important exceptions are the (n,α) reactions which are sufficiently exothermic to allow the escape from the Coulomb barrier even with thermal neutrons. The $^{6}Li(n,\alpha)$ and the $^{10}B(n,\alpha)$ reactions are in this latter category.

e. Absorption with fission (n,f). The compound nucleus splits into two or more fission fragments and one or more neutrons. Fission occurs with thermal neutrons in ^{235}U, ^{233}U, and ^{239}Pu and with fast neutrons in many heavy nuclides.

f. High energy processes. The bombardment of a nucleus with highly energetic (above 100 Mev) neutrons may result in the emission of a shower of many different types of particles.

4. NUCLEAR CROSS SECTIONS

A statistical description of neutron interaction with nuclei can be made through the use of the concept of nuclear cross sections. The concept of a nuclear cross section can be most easily visualized as the target area presented by a nucleus to an incident particle. The "size" of this target area will depend upon the energy of the incident neutron and on the particular target nuclei. This dependence on neutron energy and the target type is included in the nuclear cross section and measured in cm^2. Since nuclear cross sections often have values on the order of 10^{-24} cm^2, this quantity was arbitrarily chosen as the cross section unit; this unit is called a <u>barn</u>.

The physical significance of nuclear cross sections is that it gives a relative probability for the occurrence of a specific reaction. The higher the cross section, the higher the probability that this reaction will occur in preference to some other reaction with a lower value for its cross section.

5. NEUTRON SOURCES

There are no naturally occurring long lived radioisotopes which produce neutrons. The production of neutrons therefore depends on neutron interactions as discussed in paragraph 3. Some of the more important neutron sources which you may come in contact with are discussed below.

a. Alpha-neutron source.

In an alpha-neutron source, an alpha-emitting isotope is mixed as thoroughly as possible or combined in a chemical compound or alloy with a target material such as beryllium. The selection of the alpha-emitter may depend on a variety of parameters to include alpha-energy required, half-life and cost. Radium and polonium are commonly used alpha emitters, although others are attaining greater utilization.

Various target materials can be mixed with an alpha emitter to obtain an alpha-neutron source. The prime parameter in target material selection is the neutron yield which is different for different target materials. The yield from a given target material also depends on the alpha energy. Alphas (5.30 Mev) from polonium 210 produce neutron yields as follows:

Target	Neutrons per million alphas
Carbon	0.1
Lithium	2.7
Boron	22.0
Beryllium	77.0

The neutron yield for a specific target material varies with the alpha energy. An example for a beryllium target material is as follows:

Alpha Energy in Mev	Neutrons per million alphas
3.0	2.7
4.0	26.0
5.0	61.0
5.3	77.0

Since a beryllium target produces a relatively large neutron yield and is of low cost, it is almost always selected as the target material for small portable neutron sources.

From practical and radiological safety considerations the gamma radiation output from an alpha-neutron source must be evaluated. Gamma radiation may be present from the alpha-emitter, from the decay of target nuclei left in an excited state by the alpha-neutron reaction, and from radioactive impurities in the alpha emitter.

Exact gamma radiation outputs depend on the details of encapsulation. In evaluating the shielding of these gammas in conjunction with the neutrons, the gamma energies which vary with the type of neutron source must be considered in comparison with the relative gamma output. Shielding against gamma radiation is usually required with Ra:Be, but not with Po:Be.

b. Photoneutron sources.

Neutrons from a photoneutron source (γ,n) may be considered to be monoenergetic for most practical purposes. Photoneutron sources produce much lower yields per curie than alpha-neutron sources and are also less convenient to handle because of the numerous and energetic gammas. When a monoenergetic neutron source is desired, however, photoneutron sources may be superior to alpha-neutron sources.

Antimony-beryllium (Sb:Be) is a commonly used photoneutron source due to its relatively long half-life, high yield, and low cost.

c. Particle accelerators and nuclear reactors (fission) also produce large quantities of neutrons when operational.

6. ASPECTS OF NEUTRON SOURCES OF PARTICULAR INTEREST TO RADIOLOGICAL SAFETY ARE:

a. Certain elements when intricately mixed with select alpha emitters or in close proximity to select gamma emitters will emit copious neutrons.

b. Neutron emissions are usually accompanied by gamma radiations of varying intensities.

c. Certain neutron sources involve the emission of alpha particles and the release of radioactive radon gas.

d. Particle accelerators, nuclear reactors, and nuclear weapons are sources of neutrons.

e. Sealed neutron source capsules can leak and become a hazard. The hazard is primarily due to the initiator, such as Radium, which may emit α, β and/or γ radiation.

EQUATIONS

1. $\phi = \frac{Q}{4\pi d^2} = \frac{0.08Q}{d^2}$

where

ϕ = neutron flux (neutrons/sec-cm^2)

Q = neutron emission rate (neutrons/sec)

d = distance from neutron source (cm)

2. Neutron dose (Title 10, Sec 20.4)

$$\text{Dose} = \frac{\phi \times \text{Time}}{\text{neutrons/cm}^2 \text{ per rem}}$$

II. Lesson Objectives and Notes:

A. Characteristics of neutrons and methods of detection.

B. Calculation of neutron dose.

Notes:

III. Laboratory Exercise and/or Handouts: None

IV. Problems.

1. a. A certain neutron source has a neutron emission rate of 10^6 neutron/sec. What is the neutron flux at 1 meter? 2 meters? 3 meters?

b. What total dose would be received in 1 hour from the above source at each of the three distances? Assume all neutrons have energies greater than 10 mev.

2. A neutron gun has an emission rate of 5×10^6 n/sec. What is the maximum flux of this gun at the following distances:

a. 100 cm?

b. 10 cm?

c. 2 cm?

3. a. What total dose should be recorded if an exposure of 1004 x 10^6 n/cm^2 were received from a neutron source with the following spectra?

Energy (Mev)	Total Neutrons (%)
0.0001	71.7
0.1	11.95
2.5	11.55
7.5	4.78

b. What total dose would be recorded if the spectrum was unknown?

V. Solutions to Problems.

1. a. At 1 meter

$$\phi = \frac{0.08\,Q}{d^2}$$

$$= \frac{0.08(10^6)}{(100)^2}$$

$$= 8\ \frac{n}{\text{sec-cm}^2}$$

At 2 meters

$$\phi = \frac{0.08(10^6)}{(200)^2}$$

$$= 2\ \frac{n}{\text{sec-cm}^2}$$

At 3 meters

$$\phi = \frac{0.08(10^6)}{(300)^2}$$

$$= 0.89\ \frac{n}{\text{sec-cm}^2}.$$

b. One hour = 3600 sec.

Dose at 1 meter.

$$8\ \frac{n}{\text{sec-cm}^2}\left(\frac{3600\text{ sec}}{1}\right)\left(\frac{1\text{ rem}}{14\times10^6\ \frac{n}{\text{cm}^2}}\right) = 2.06 \times 10^{-3}\text{ rem}$$

$$= 2.06\text{ mrem}$$

Dose at 2 meters

$$\left(2\ \frac{n}{\text{sec-cm}^2}\right)(3600\ \text{sec})\left(\frac{1\ \text{rem}}{14\text{x}10^6\ \frac{n}{\text{sec}}}\right) = \underline{\underline{0.51\ \text{mrem}}}$$

Dose at 3 meters

$$\left(0.89\ \frac{n}{\text{sec-cm}^2}\right)(3600\ \text{sec})\left(\frac{1\ \text{rem}}{14\text{x}10^6\ \frac{n}{\text{sec}}}\right) = \underline{\underline{0.229\ \text{mrem}}}$$

2. a. $\phi = \dfrac{0.08\ Q}{d^2}$

$\phi = \dfrac{0.08(5\text{x}10^6)}{(100)^2}$

$= 40\ n/\ cm^2/\ sec$

b. $\phi = \dfrac{0.08(5\text{x}10^6)}{(10)^2}$

$= 4.0 \times 10^3\ n/\ cm^2/\ sec$

c. $\phi = \dfrac{(0.08)(5\text{x}10^6)}{(2)^2}$

$= 1 \times 10^5\ n/cm^2/sec$

3. a. Calculate total neutrons at each energy.

(0.0001 Mev) 1004×10^6 n/cm^2 (0.717) = 720×10^6 n/cm^2

(0.1 Mev) 1004×10^6 n/cm^2 (0.1195) = 120×10^6 n/cm^2

(2.5 Mev) 1004×10^6 n/cm^2 (0.1155) = 116×10^6 n/cm^2

(7.5 Mev) 1004×10^6 n/cm^2 (0.0478) = 48×10^6 n/cm^2

From 10CFR20 get values of neutrons/cm^2 to cause 1 rem dose for each energy.

Energy (Mev)	Neutrons/cm^2/rem
0.0001	720×10^6
0.1	120×10^6
2.5	29×10^6
7.5	24×10^6

Calculate dose by dividing total neutron exposure by neutrons/cm^2/rem for each energy.

$$\text{Dose} = \frac{720 \times 10^6}{720 \times 10^6} + \frac{120 \times 10^6}{120 \times 10^6} + \frac{116 \times 10^6}{29 \times 10^6} + \frac{48 \times 10^6}{24 \times 10^6}$$

$$= 1 + 1 + 4 + 2$$

$$= \underline{\underline{8 \text{ rem}}}$$

b. When spectrum is unknown 10CFR20 allows you to use the value of 14×10^6 n/cm^2 equal to 1 rem.

$$\text{Dose} = \frac{\text{Total neutrons/cm}^2}{\text{Neutrons/cm}^2\text{/rem}}$$

$$= \frac{1004 \times 10^6}{14 \times 10^6}$$

$$= \underline{\underline{71.7 \text{ rem}}}$$

This would be the dose recorded if the spectrum was unknown even though the actual dose in this case was only 8 rem.

SHIELDING PROPERTIES OF MATERIALS

DF230

DF230, SHIELDING PROPERTIES OF MATERIALS

I. References and Discussion: ST 3-155, para 4.10; Radl Saf Handbook DF230.

A. Review of Interactions of Gamma Rays with Matter.

1. Gamma radiation is attenuated by three processes:

   a. Photoelectric effect - where the gamma photon strikes the orbital electron and gives up all of its energy to the electron, ejecting it from the atom.

   b. Compton effect - where the gamma photon strikes the orbital electron and gives part of its energy to the electron. The remaining energy goes off as a weaker gamma capable of producing more ionization before its energy is completely used up. The ejected electron acts the same as low-energy beta particles.

   c. Pair production - where the gamma photon passes in close proximity to the nucleus of an atom and is converted into an electron and a positron. Later the positron will recombine with an electron and produce two other gamma photons of lesser energy which will be attenuated by the photoelectric or Compton effect.

2. Since the photoelectric and Compton effects depend upon interaction with electrons, materials with large numbers of electrons per unit volume will make the best gamma shielding materials. For this reason, dense materials like lead, steel, and concrete are some of the better shielding materials.

3. For gamma radiation to be attenuated the gamma photons must strike an electron or pass very close to a nucleus. The probability of this happening is not very great, because of the vast amount of space existing within any material. Theoretically, then, some gamma photons will always pass through any amount of material without being attenuated. However, we can appreciably decrease the gamma dose rate by using good shielding materials.

4. Graphical Solution to Shielding Problems.

   a. Shielding problems may be solved by a graphical method. Semi-logarithmic graph paper is used for this purpose. The vertical scale is logarithmic and will be used to plot dose rates. The linear horizontal scale will be used for shield thickness.

b. The first step is to mark off the axes of the graph paper. Look at the graph paper on the next page. The dose rate (log) scale is divided into decades, or powers of ten. You must determine how many cycles are necessary to represent the range of dose rates of interest. To do this, take the maximum dose rate expected and the minimum dose rate expected to determine the range. Then determine how may cycles (powers of ten) are needed to cover this range. For example, if the range is from 8 rad/hr to 80 rad/hr, two cycles are necessary; one cycle from 1 to 10 and one cycle from 10 to 100 as shown on the graph on page 322.

c. To solve a shielding problem by the graphical method, certain information must be available. The unshielded dose rate (R_o), shielded dose rate (R), shield thickness (X) and shield half-thickness ($X_{\frac{1}{2}}$) are variables which must be determined.

Half thickness is that thickness of a material required to reduce the unshielded dose rate at a point to one-half its original value. Given any three of these the fourth may be determined graphically.

d. Example Problem.

The unshielded dose rate at a point is 80 rad/hr. It is desired to place a shield of half-thickness 10 cm in such a way as to reduce the dose rate to 15 rad/hr. What thickness of shield is required?

Solution: (See page 321)

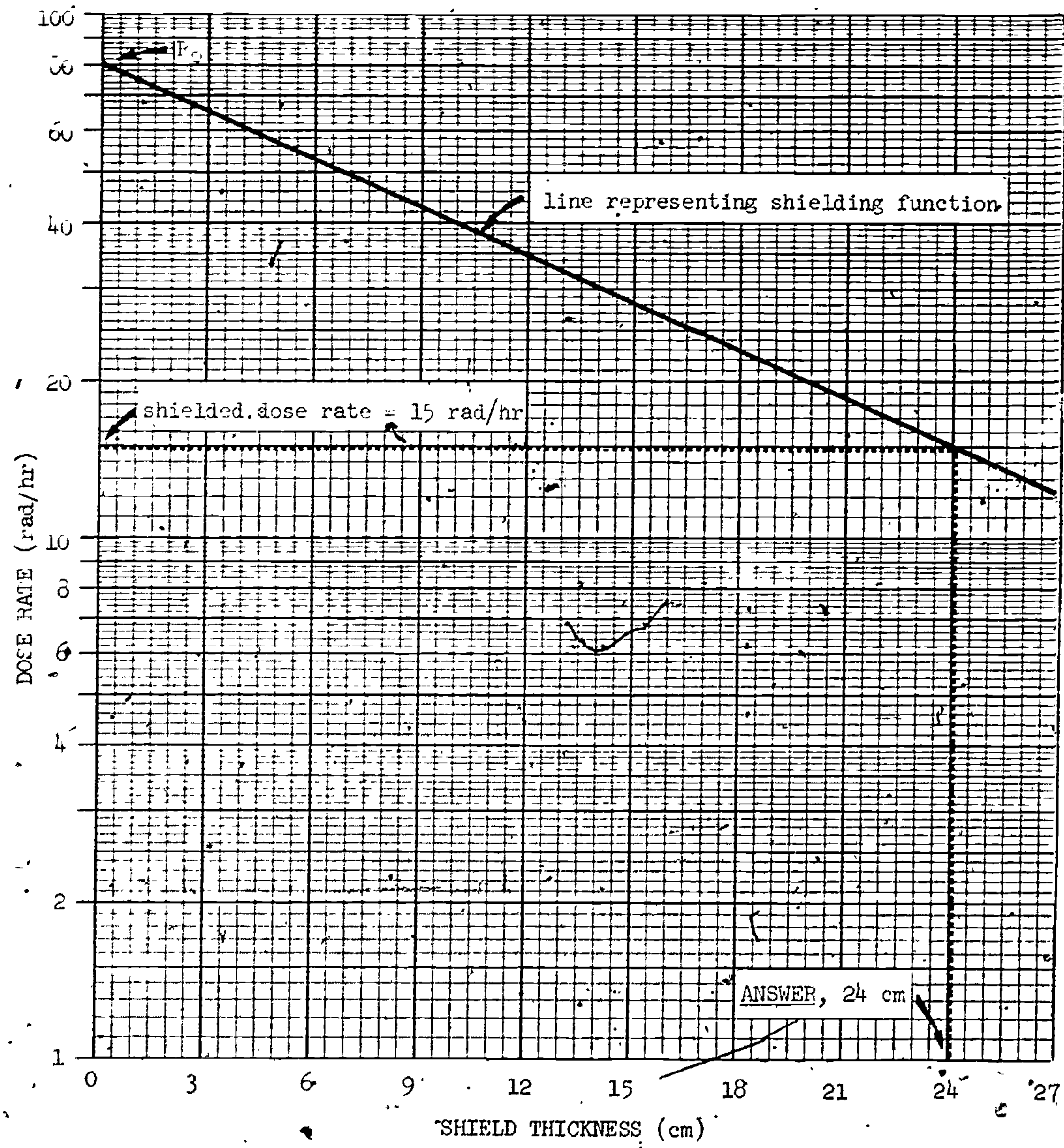
Assume the shield has zero thickness, the dose rate will be 80 rad/hr. Locate the point corresponding to 0 thickness and 80 rad/hr on the graph and mark it. Assume the shield is 10 cm thick, since this is one half-thickness the dose rate will be reduced to 40 rad/hr. Locate the point on the graph corresponding to 10 cm, 40 rad/hr and mark it. Draw a straight line through the two points located on the graph. This line represents the dose rate corresponding to any shield thickness for a shield made of this material. To determine the thickness required to reduce the dose rate to 15 rad/hr, locate 15 rad/hr on the dose rate scale, read to the right until you reach the line. Read down from the line to the thickness scale and find that 24 cm of material will be required as the shield.

5. Mathematical Solution to Shielding Problems.

In a previous class (DF100) you were introduced to the shielding equation:

$$R = R_o e^{-\mu x} \quad \text{where} \qquad (1)$$

GRAPHICAL SOLUTION TO SHIELDING PROBLEMS



$R' = $ Shielded dose rate

$R_o = $ Unshielded dose rate

$\mu = $ Total linear absorption (attenuation) coefficient

$X = $ Shield thickness

You also were shown the relationship of half-thickness and the equation

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} \quad (2)$$ was developed.

This expression is energy dependent because μ varies with the energy of the gamma ray under consideration. In order to obtain an equation which may be used for an approximate solution, it is necessary to assume a constant energy spectrum which would make μ independent of energy. If this is done, we may rewrite equation (2).

$$\mu = \frac{0.693}{X_{\frac{1}{2}}} \qquad (3)$$

substituting into equation (1)

$$R = R_o e^{-\left(\frac{0.693}{X_{\frac{1}{2}}}\right) X} \qquad (4)$$

taking logarithms

$$\ln R = \ln R_o - \frac{X}{X_{\frac{1}{2}}} (0.693) \qquad (5)$$

but $0.693 = \ln 2$ so

$$\ln R = \ln R_o - \frac{X}{X_{\frac{1}{2}}} \ln 2 \qquad (6)$$

Taking antilogarithm of the above expression we get

$$R = \frac{R_o}{2^{\frac{X}{X_{\frac{1}{2}}}}} \qquad (7)$$

If we let $n = \frac{X}{X_{\frac{1}{2}}}$ (8)

equation (7) becomes

$$R = \frac{R_o}{2^n} \qquad (9)$$

Equations (8) and (9) are the equations we will use to solve shielding problems for field approximation.

6. Use of the 2^n Tables.

The table in the back of the Radiological Safety Handbook in the Radiological Safety Handbook Supplement, and in ST 3-155, pages 50-51; lists values of 2^n corresponding to a range of values for n. It is desirable to safe-side the answers to out shielding problem so, rather than interpolating between values in the table, a guide is provided for selecting values from the table. This guide appears at the top of the 2^n Table.

The use of the guide for safe-siding depends on the variable which is unknown. For example, if the thickness is unknown, find X in the "unknown" column, read to the right. Find that you should enter the table with 2^n, select the larger value of 2^n and leave the value of n corresponding to that larger value.

7. Effect of Shield Position on Dose Rate.

a. Due to the scattering which occurs when a beam of gamma rays passes through a shield (Compton effect) there is an angular distribution to those radiations emerging from the shield. If the shield (see fig 1(a)) is placed close to the detector, a number of scattered radiations will contribute to the dose rate. If the shield is placed further away from the detector

diagram

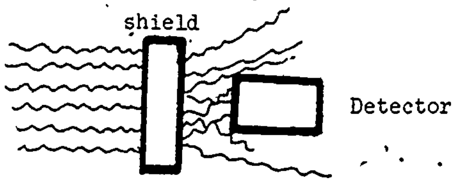
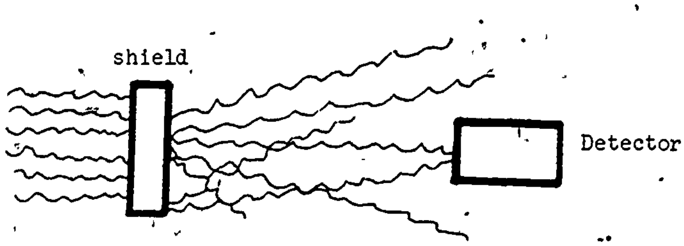


Figure 1. (a) Detector close to shield



(b) Shield further from detector

a number of the scattered radiations detected when the shield was close to the meter now are not detected. This gives a lower dose rate than that seen originally. This phenomenon is known as dose rate buildup.

The equations discussed previously in paragraph 5 do not hold when the detector is close enough to the shield that dose rate buildup is observed. For this particular problem a correction must be made to account for dose rate buildup. The dose rate buildup factor "b" is applied to Equation (1) to obtain

$$R = bR_o e^{-\mu x} \qquad (10)$$

This buildup factor may be determined from charts in Pam 25. On pages 145-147, Pam 25, are the dose rate buildup factors for various materials.

When a dose rate buildup chart is not available for a shielding material, an approximation may be made by substituting the value of μx for b. However, if μx is less than 1, use 1 for b (i.e., ignore dose rate buildup).

b. Another method for accounting for dose rate buildup is found in FM 3-8. This section is self-explanatory and contains an example problem which you should go through to insure your understanding of the method.

II. Student Performance Objectives and Notes.

A. Given text, references, student notes, the radioisotope, number of curies, and specified shielding material, calculate the thickness of shielding material (or materials) necessary to reduce the dose rate to a given level. (Be capable of performing all types of basic shielding problems.)

B. Using texts, references, student notes, a known unshielded dose rate, and radiac instruments, perform laboratory measurement using various shielding materials to determine the half-thickness of these shielding materials.

Notes:

III. Practice Problems.

1. GIVEN: $R_o = 2000$ rad/hr

   $X = 31$ cm

   $X_{1/2} = 4$ cm

   FIND: R

2. GIVEN: $R_o = 1000$ rad/hr

   $X = 27$ cm

   $R = 7.60$ rad/hr

   FIND: $X_{1/2}$

3. GIVEN: $R_o = 1500$ rad/hr

$X_{1/2} = 5.5$ cm

$R = 3.5$ rad/hr

FIND: X

4. GIVEN: $X = 60$ cm

$X_{1/2} = 5.2$ cm

$R = .5$ rad/hr

FIND: R_o

5. How much lead is necessary to reduce the gamma dose rate to 2 mrad/hr at 4 meters from a 20 curie source of Cesium-137?

6. What will the gamma dose rate at 3 meters from an 8 curie source of Iron-59 be if it is shielded by a 5 cm block of spent uranium?

7. How much water fill must be used to insure the dose rate at the top of a 4 meter deep pit does not exceed 2 mrad/hr if a 15 curie ^{60}Co source is placed in the bottom of the pit?

IV. Solution to Practice Problems.

1. Solve equation $n = \frac{X}{X_{1/2}}$ for n.

$$n = \frac{X}{X_{1/2}} = \frac{31 \text{ cm}}{4 \text{ cm}} = 7.75$$

Enter 2^n Table in the n column and find n = 7.7 and 7.8. From the guide table select smaller n value of 7.7. Read corresponding 2^n value of 206. Substitute R_o and this 2^n value in equation (1).

$$R = \frac{2000 \text{ rad/hr}}{206} = 9.71 \text{ rad/hr}$$

2. GIVEN: R_o = 1000 rad/hr; X = 27 cm; R = 7.60 rad/hr

FIND: $X_{1/2}$

First solve $R = \frac{R_o}{2^n}$ for 2^n.

$$2^n = \frac{R_o}{R} = \frac{1000 \text{ rad/hr}}{7.6 \text{ rad/hr}} = 132$$

Enter 2^n table in 2^n column and find 2^n = 128 and 136.

From guide table, select smaller 2^n of 128. Read corresponding n value of 7.0. Substitute X and this n value in equation (2).

$$X_{1/2} = \frac{X}{n} = \frac{27 \text{ cm}}{7.0} = 3.86 \text{ cm.}$$

3. GIVEN: R_o = 1500 rad/hr; $X_{1/2}$ = 5.5 cm; R = 3.5 rad/hr.

FIND: X

First solve equation (1) for 2^n.

$$2^n = \frac{1500 \text{ rad/hr}}{3.5 \text{ rad/hr}} = 429$$

Enter 2^n Table in 2^n column and find 2^n = 415 and 445. From guide table, select larger 2^n of 445. Read the corresponding n value of 8.8. Substitute $X_{1/2}$ on this value in equation (2).

$$X = nX_{1/2} = (8.8)(5.5 \text{ cm}) = 48.4 \text{ cm}$$

4. GIVEN: $X = 60.0$ cm; $X_{\frac{1}{2}} = 5.20$ cm; $R = 5.00$ rad/hr

FIND: R_o

First solve equation (2) for n.

$$n = \frac{X}{X_{\frac{1}{2}}} = \frac{60.0 \text{ cm}}{5.20 \text{ cm}} = 11.53$$

Enter 2^n Table in n column and find n = 11.5 and 11.6. From Guide Table select large n value of 11.6. Read corresponding 2^n value of 3110. Substitute R value and this value in equation (1).

$$R_o = R2^n = (5.00 \text{ rad/hr})(3110) = \underline{\underline{15,550 \text{ rad/hr}}}$$

5. R_o =

R = 2 mrad/hr

X =

$X_{\frac{1}{2}}$ =

Find R_o. Go to page 399 of Pam 25 - decay scheme for ^{137}Cs.

From the scheme E_γ = 0.6616 (93.5%).

$$S = 0.56 \text{ n CE}$$

$$S = (0.56)(0.935)(20)(0.6616)$$

$$S = 6.93 \text{ rhm}$$

$$R_o = \frac{S}{d^2} = \frac{6.93}{(4)^2} = \frac{6.93}{16} = 0.434 \text{ rad/hr or } 434 \text{ mrad/hr}$$

Find $X_{\frac{1}{2}}$. Go to page 303, Pam 25 - find most energetic gamma ($\geq 3\%$). μ/ρ for 0.662 Mev in lead from page 138.

μ/ρ for 0.6 Mev	=	0.1250	0.662
μ/ρ for $\underline{0.8}$ Mev	=	$\underline{0.0885}$	$\underline{0.600}$
0.2 Mev		0.0365	0.062

$$\frac{62}{200} \text{ or } \frac{31}{100} = 0.31$$

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$0.31 \times 0.0365 = 0.0113$

μ/ρ for 0.6 Mev = 0.1250
$$\begin{array}{r} -0.0113 \\ \hline 0.1137 \end{array} = \mu/\rho \text{ for } 0.662 \text{ Mev}$$

ρ for lead = 11.35 gm/cm^3 (page 65).

$$\mu = \mu/\rho \times \rho = 0.1137 \times 11.35$$

$$\mu = 1.29 \text{ cm}^{-1}$$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{1.29} = 0.537 \text{ cm}$$

Find X.

$$2^n = \frac{R_o}{R} = \frac{434}{2} = 217$$

$$n = 7.8 \text{ (using large } 2^n)$$

$$X = nX_{\frac{1}{2}}$$

$$X = (7.8)(0.537 \text{ cm})$$

$$X = \underline{\underline{4.19 \text{ cm}}}$$

6. R_o =

R =

X = 5 cm

$X_{\frac{1}{2}}$ =

Find R_o. Go to page 388 of Pam 25 - decay scheme for ^{59}Fe.

$E_{\gamma 1}$ = 1.095 (53%)

$E_{\gamma 2}$ = 1.292 (45%)

$E_{\gamma 3}$ = 1.435 (1.1%) not used < 3%.

$$S_{\gamma 1} = 0.56 \text{ n CE}$$
$$= (0.56)(0.53)(8)(1.095)$$
$$= 2.599 \text{ or } 2.6 \text{ rhm}$$

$$S_{\gamma 2} = 0.56 \text{ n CE}$$
$$= (0.56)(0.45)(8)(1.292)$$
$$= 2.604 \text{ or } 2.6 \text{ rhm}$$

$$S_T = S_1 + S_2$$
$$= 2.6 + 2.6$$
$$S_T = 5.2 \text{ rhm or } 5200 \text{ mrhm}$$

$$R_o = \frac{S}{d^2} = \frac{5200}{(3)^2} = \frac{5200}{9} = 578 \text{ mrad/hr}$$

Find $X_{\frac{1}{2}}$. Go to page 248, Pam 25 - find most energetic gamma ($\geq 3\%$)? μ/ρ for 1.292 Mev -

μ/ρ for 1 Mev	= 0.0776		1.292
μ/ρ for 1.5 Mev	= 0.0548		1.000
0.5 Mev	0.0228		0.292

$$\frac{0.292}{0.5} = 0.584$$

$$0.584 \times 0.0228 = 0.0133$$

$$\begin{array}{r} 0.0776 \\ -0.0133 \\ \hline 0.0643 \end{array} = \mu/\rho \text{ for } 1.292 \text{ Mev}$$

$$\rho \text{ for Uranium} = 18.68 \text{ gm/cm}^3$$

$$\mu = \mu/\rho \times \rho = (0.0643)(18.68)$$
$$\mu' = 1.2 \text{ cm}^{-1}$$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{1.2} = 0.5775 \text{ cm or } 0.58 \text{ cm}$$

$$n = \frac{X}{X_{\frac{1}{2}}} = \frac{5}{0.58} = 8.62$$

smaller value - use 8.6. $2^n = 385$

$$2^n = \frac{R_o}{R}$$

$$R = \frac{R_o}{2^n} = \frac{578 \text{ mrad/hr}}{385}$$

$$R = \underline{\underline{1.5 \text{ mrad/hr}}}$$

7. $R_o =$

$R = 2$ mrad/hr

$X =$

$X_{\frac{1}{2}} =$

Find R_o. Go to page 389, Pam 25.

$E_\gamma = 2.5057 \quad (99\%)$

$S = 0.56 \text{ n Ci E}$

$S = (0.56)(0.99)(15)(2.5057)$

$S = 20.8$ rhm

$$R_o = \frac{S}{d^2} = \frac{20.8}{(4)^2} = \frac{20.8}{16} = 1.3 \text{ rad/hr or } 1300 \text{ mrad/hr}$$

Find $X_{\frac{1}{2}}$. Go to page 249, Pam 25 - find most energetic gamma ($\geq 3\%$). μ/ρ for 1.332 Mev -

μ/ρ for 1 Mev =	0.0707	1.332
μ/ρ for 1.5 Mev =	0.0575	-1.000
0.5	0.0132	0.332

$$\frac{0.332}{0.5} = 0.664$$

$$0.0132 \times 0.664 = 0.00876$$

$$\begin{array}{r} 0.07070 \\ -0.00876 \\ \hline 0.06194 \end{array} = \mu/\rho \text{ for } 1.332 \text{ Mev in water.}$$

ρ for water = 1 gm/cm^3 (page 66, Pam 25)

$\mu = \mu/\rho \times \rho$

$\mu = 0.06194 \times 1$

$\mu = 0.06194 \text{ cm}^{-1}$

$X_{\frac{1}{2}} = \frac{0.693}{0.06194} = 11.2 \text{ cm}$

Find X.

$2^n = \frac{R_o}{R} \doteq \frac{1300}{2} = 650$

$n = 9.4$

Use larger value.

$X = nX_{\frac{1}{2}}$

$X = (9.4)(11.2)$

$X = 105 \text{ cm}$

$X = \underline{\underline{1.05}}$ meters of water in the pit.

STUDENT NO. ________________

CLASS ________________

DATE ________________

INSTRUCTOR ________________

SCORE ________________

SHIELDING PROPERTIES OF COMMON MATERIALS

V. Laboratory Exercise.

A. Instructions.

1. The purpose of this exercise is to determine the half-thickness in centimeters and relative order of shielding ability for the materials listed on the Data Sheet.

2. Perform a pre-operation check of the radiacmeters, and turn the selector switch to the 0 to 50 mrad/hr scale.

3. The radioactive source is located in the center of the shielding device. There are twelve arms on the shielding device, each arm has a carrying hook on the bottom for holding the various shields. Place the radiacmeter on the floor under one of the arms. Move the radiacmeter until an unshielded reading of 40 mrad/hr is obtained. Enter this as the unshielded dose rate (R_o) on your data sheet.

4. Place a shield on the carrying hook and move it until the shield is close to the meter. Adjust the turnbuckle on the arm support cable, if necessary, until the shield almost touches the floor.

5. Move the shield slowly away from the meter observing the meter dial continuously. Note the minimum reading obtained while the shield traverses the length of the shielding device arm. Record this minimum reading as the shielded dose rate (R) on your data sheet. Obtaining a minimum reading helps minimize effects due to dose rate buildup and scattering from the surroundings.

6. Using a meter stick or rule, measure the shield thickness in centimeters and enter it in your data sheet under (X). In measuring the thickness of the shields, include the thickness of lucite containers for sand and water. These lucite containers have a minimal thickness; therefore, it is more correct to measure them than to neglect them.

B. Data.

DATA SHEET - SHIELDING

Instrument Type ______________________ Date ______________

Instrument Serial No. ______________________

SHIELDING MATERIAL	(R_o) UNSHIELDED DOSE RATE	(R) SHIELDED DOSE RATE	(X) THICKNESS OF SHIELD	($X_{\frac{1}{2}}$) HALF-THICKNESS
UNITS	mrad/hr			
LEAD				
WOOD				
STEEL				
CONCRETE				
SAND				
WATER				
ALUMINUM				
LUCITE				

What is the relative order of shielding ability of the materials tested?

Lead

Wood

Steel

Concrete

Sand

Water

Aluminum

Lucite

C. Homework Problems.

These problems will be turned in with the Laboratory Exercise as a portion of the graded requirement for this course.

SECTION I - Problems using 2^n Procedure

1. It is desired to construct a wall of reinforced concrete to provide shielding for certain instrumentation in a reactor room. The unshielded dose rate at the position to be occupied by the instruments is 200 rad/hr when the reactor is in operation. It is desired to reduce this reading to 100 mrad/hr.

   a. What is the thickness of concrete necessary to provide this shielding if the half-thickness of concrete is 10 cm?

   b. What would the dose rate be if 6 feet of concrete were used?

   c. Suppose a layer of the wall could be made of lead plate 2 cm thick. What thickness of concrete would be necessary in addition to the lead to meet the original requirement? ($X_{1/2}$ lead = 1 cm)

2. A radioactive source (.5 rhm) is being stored in a lead-walled cave. How thick must these walls be so that the dose rate 1.5 meters from the source is such that the area beyond this distance will not have to be marked "high radiation area" (see Title 10)? $X_{1/2}$ lead = 1 cm.

3. The dose rate at a point 1.75 meters from a radioactive source is 1600 mrad/hr. If a wall 60 cm thick is erected 90 cm from the source, what will be the dose rate at 1.75 meters if the half-thickness of the wall material is 20 cm? (Neglect dose rate buildup.)

4. A man standing 5 meters from the outside of a storage vault receives a dose rate of 18 mrad/hr. How many centimeters of concrete must be added to the shield such that the dose rate he receives will be reduced to 0.8 mrad/hr? Assume half-thickness of concrete = 7.5 cm.

5. You are required to build a vault to store ^{60}Co. The outside face of the vault wall must be 4 meters from the source. The unshielded dose rate at 4 meters from the source is 5 rad/hr. The wall must be capable of reducing the dose rate to 5 mrad/hr at the outside face of the wall. You have on hand concrete blocks 9 cm thick, and loose sand. You decide to build a double wall of concrete blocks to be filled in with sand. How thick (in centimeters) must the layer of sand be? (Neglect dose rate buildup.)

ASSUME: Half-thickness of concrete = 7.5 cm
Half-thickness of sand = 12.5 cm

6. What is the half-thickness of air for 1 mev gamma radiation?

GIVEN: Density of air = 1.3×10^{-3} (gm/cm^3)

Mass attenuation coefficient = 0.061 (cm^2/gm)

7. You are planning a hot cell to handle gamma emitters in the 0.1-5 Mev energy range. The largest sources to be handled will be 5000 rhm and the nearest they will come to the inside of the wall will be 50 cm. Neglecting dose buildup, the dose rate 2 meters from the inner surface of the wall must not exceed 5 mrad/hr. The inner portion of the wall will be a 2 cm thick sheath of lead. The rest of the wall will be of concrete of density 2.8 gm/cm^3. How thick must the concrete be? (Use table on page 139, Pam 25, for concrete, use table on page 138 for lead.)

8. As radiological safety officers, you have been given an unknown single radionuclide. Upon receipt, one of your assistants measured the dose rate, unshielded, as being 980 mrad/hr at a distance of 2 meters. Six days later another of your assistants measures the dose rate as 160 mrad/hr at a distance of 3 meters. What is the half-life of this radionuclide?

SCINTILLATION INSTRUMENTS

DF241

DF241. SCINTILLATION INSTRUMENTS

I. Reference: ST 3-155, Chapter 9.

II. Lesson Objectives and Notes.

A. Explain the theory of scintillation.

B. Describe scintillation instrument capabilities and limitations.

Notes:

III. Handouts:
1. Definition of Terms
2. Vu-Graphs

IV. Problems: None.

V. Solutions: None.

Definition of Terms Used in
Scintillation Detection of Radiation

1. Scintillation - physically emits sparks.

2. Luminescence- release of absorbed energy in the form of ultraviolet light, visible light, or infrared radiation.

3. Fluorescence - luminescence that occurs within 1×10^{-6} sec after the absorption of energy.

4. Phosphorescence - luminescence that occurs after 1×10^{-6} sec (and may be as long as several days) after the absorption of energy.

5. Chemiluminescence - chemical absorption of energy later released as light.

6. Bioluminescence - chemiluminescence in living organisms, i.e., firefly.

7. Photoluminescence - absorption of ultraviolet light, visible light, or infrared radiation later released as light.

8. Radioluminescence or Roentgenoluminescence - X or gamma radiation absorption later emitted as light.

9. Triboluminescence - absorption of energy from grinding or friction later emitted as light.

10. Thermal Luminescence - absorption of heat later emitted as light.

11. Thermoluminescence - process of emitting absorbed energy when heat is applied to the material.

12. Activator - impurity added to luminescent material to shift the electromagnetic emission from the ultraviolet to the visible light range. An example is Thallium in Sodium iodide and is indicated as NaI (Tl).

13. Photoelectron - electron that receives all the energy of gamma or X radiation.

14. Ground State of Electron - normal energy level of electron.

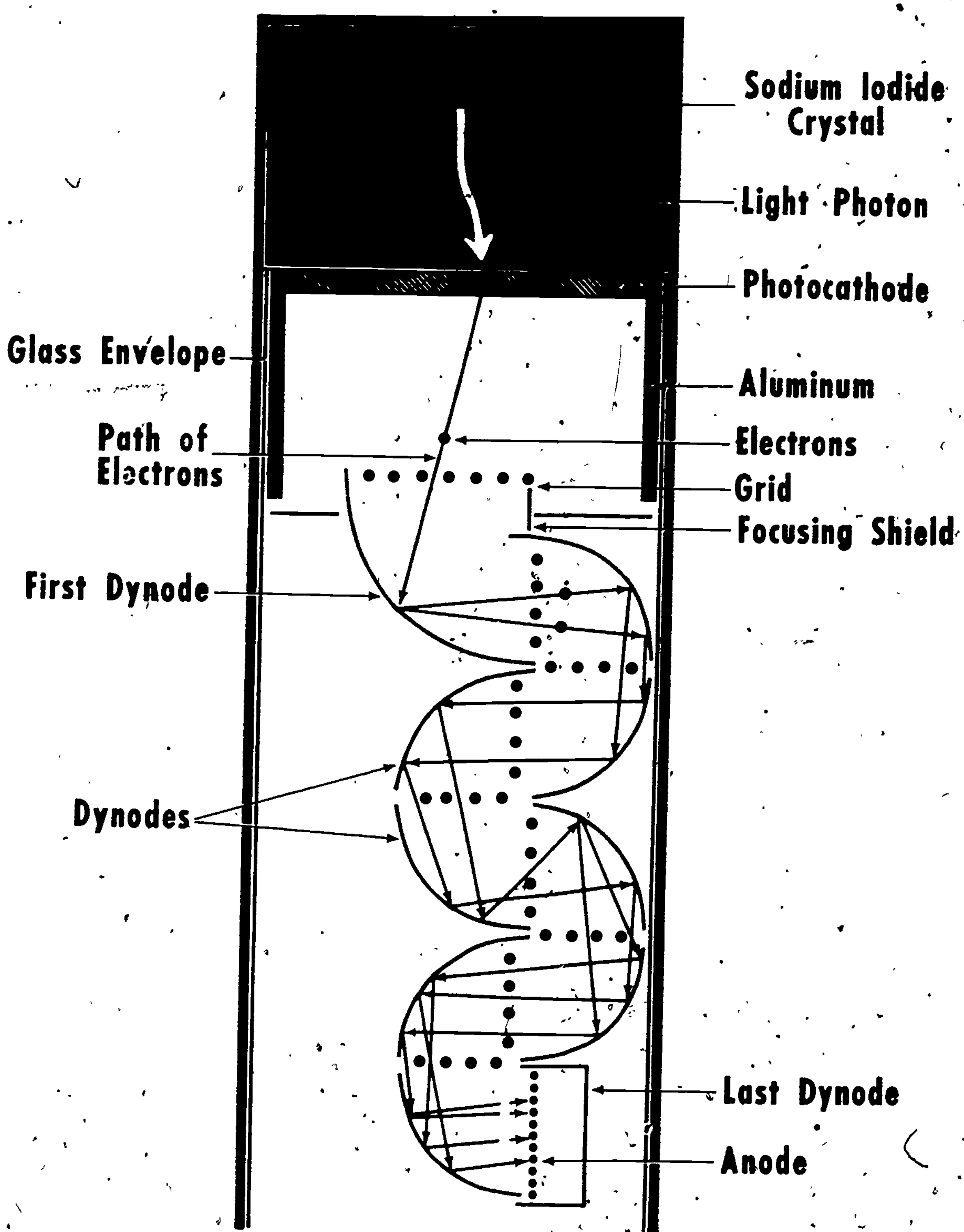
15. Excited State of Electron - permitted higher energy level of an electron but still not an ion state.

16. Photomultiplier Tube - an electron tube with a light sensitive cathode used to detect light.

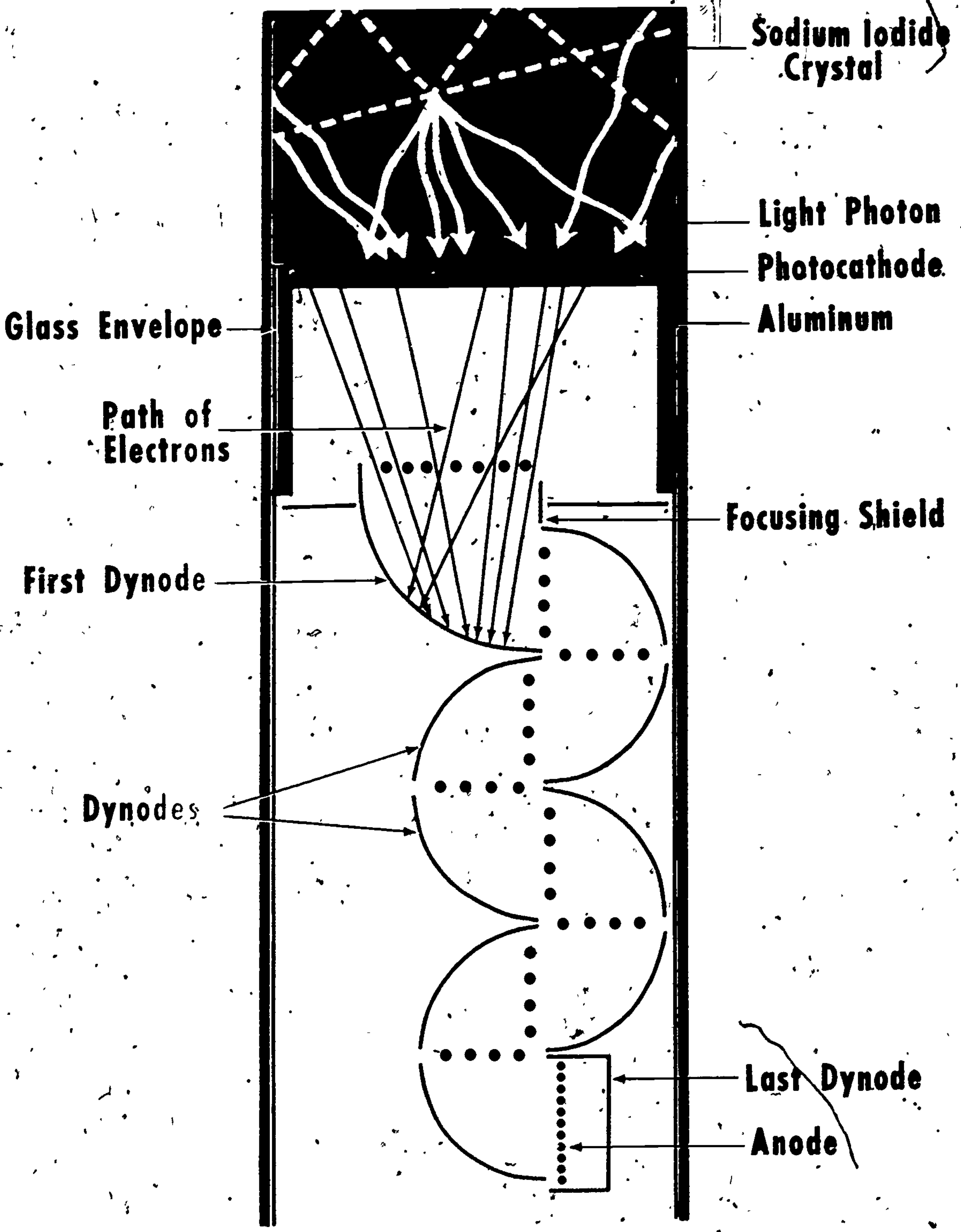
17. **Photocathode** - the light sensitive cathode of a photomultiplier tube. Cesium antimony is an example.

18. **Dynode** - electronic part of photomultiplier tube that performs both as a cathode and anode.

PHOTOMULTIPLIER TUBE



PHOTOMULTIPLIER TUBE



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ALPHA INSTRUMENTS

DF250, ALPHA INSTRUMENTS

I. Reference: ST 3-155, Chapter 10, Appendix I, Section C & D, Appendix IV, V, and VI.

II. Lesson Objectives and Notes:

A. Characteristics of alpha contamination.

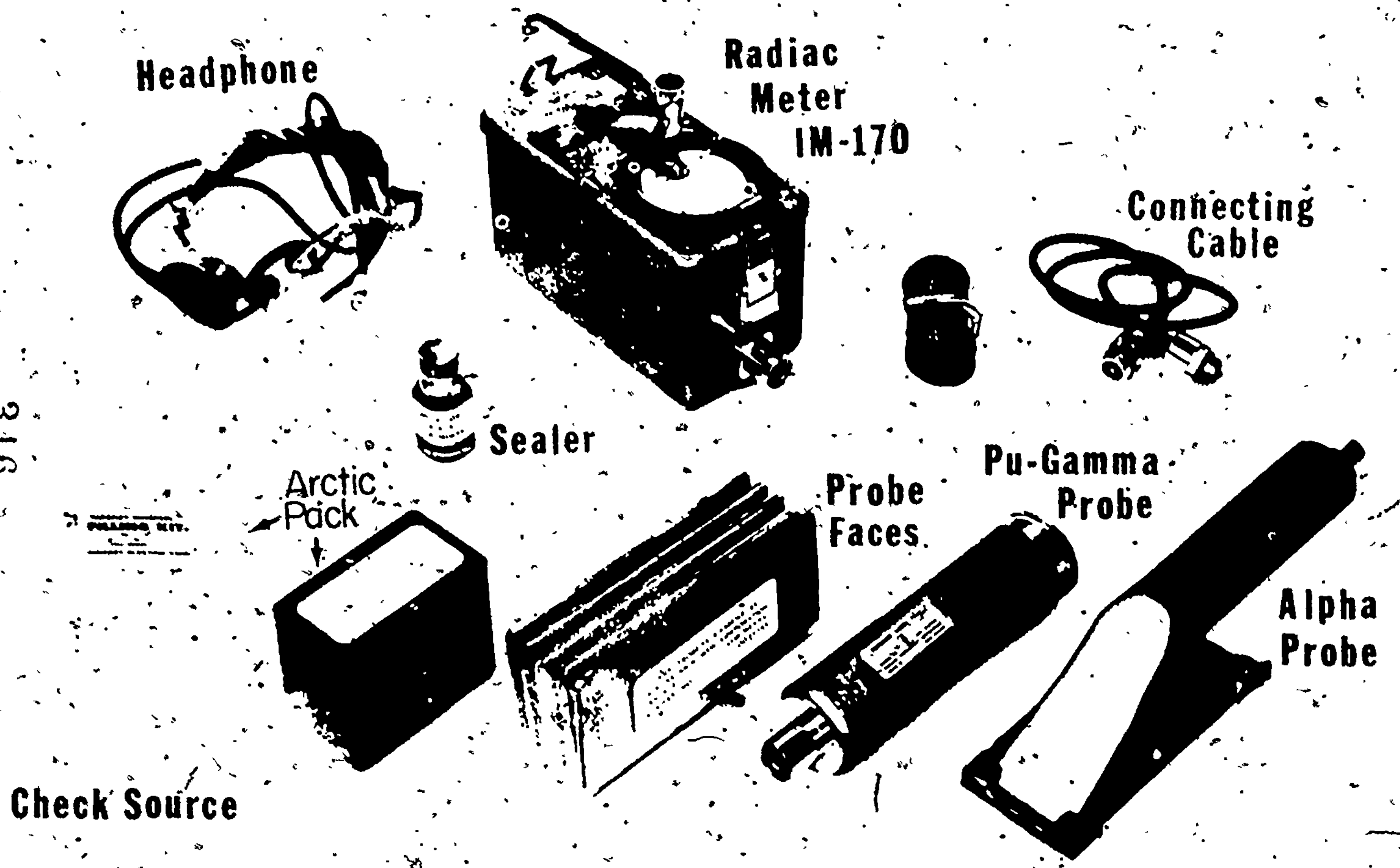
B. Alpha instruments and their use.

C. Methods of reporting levels of alpha contamination.

RADIAC SET AN/PDR-60 WITH CARRYING CASE

C359-65

COMPONENTS OF RADIAC SET AN/PDR-60



C358-65

III. Laboratory Exercise: None

IV. Problem.

Class and Home Study Problem.

The following readings were obtained by monitors at an accident site. What are the levels of alpha contamination for each reading?

	Instrument	Type of Surface	Meter Reading	$\frac{\mu g\,^{239}Pu}{M^2}$
a.	IM-170	Soil	204,000 cpm	
b.	IM-170	Wood floor	1,080,000 cpm	
c.	IM-170	Jeep hood	1,340,000 cpm	
d.	IM-170	Hard surface road	952,000 cpm	

V. Solution to Problem.

Solution to Class and Home Study Problem.

General: $\frac{\mu g^{239}Pu}{M^2} = R(CF)$

where R = Meter Reading

CF = Correction Factor

therefore:

	Correction Factors*	Meter Reading	$\frac{\mu g^{239}Pu}{M^2}$
a.	$\frac{1}{170}$	204,000	1,200
b.	$\frac{1}{240}$	1,080,000	4,500
c.	$\frac{1}{400}$	1,340,000	3,350
d.	$\frac{1}{200}$	952,000	4,760

*Obtained from Table I-2, ST 3-155.

THE ARMY RADIAC INSTRUMENT CALIBRATION SYSTEM

DF 260

DF260, THE ARMY INSTRUMENT CALIBRATION SYSTEM

I. Reference and Discussion.

A. Reference: ST 3-155, para 14.4-14.7, App I, para E.

B. Discussion:

In the event of a nuclear war the field commander will need information concerning the amount of radiological contamination in his area of operations. This information will come from numerous survey and monitoring teams. It will be of little value if the radiac instruments used to measure the dose rate due to the contamination do not give readings which are correct within certain acceptable limits.

Radiac instruments, like all electronic instruments, require periodic calibration. In the case of radiac instruments, the causes of incorrect readings may be broken into three general categories: environmental, electronic, and radiological.

Environmental causes of error, or loss of calibration, are a result of atmospheric conditions and the way in which a meter is used. Shaking or vibrating may cause a meter to lose its calibration. Rough treatment may cause mechanical vibrations within the meter. The response of radiac instruments may be affected by temperature, humidity, and atmospheric pressure. Military specifications for Army radiac instruments require that they give a linear (the same) response in all temperature, pressure, and moisture conditions in which the instrument might be conceivably expected to exist or operate.

Errors which are considered to be due to a radiological phenomena may be due to different energies and types of radiation. Specifications for military gamma radiation intensity measuring instruments require that they give a linear response (the same reading) for all energies of gamma radiation between 80 kev and 4 mev which is the expected range of energies of fission products.

In order to correct for errors which come about in the handling and storage of radiac instruments, they should be calibrated periodically.

The Army system for calibration of radiac instruments consists of a series of reference and transfer standards. All standards and radiac instruments are referred to the National Primary Standard at the National Bureau of Standards through the Army Primary Reference Standard. The Army Primary Reference Standard is a 500 curie cobalt-60 source maintained at Lexington Army Depot. Secondary reference standards are located at Sacramento Army Depot and several oversea depots. The standard at Sacramento is a 500 curie cobalt-60 source. Those in oversea depots are AN/UDM-1A's.

Notes:

II. Handouts: None.

III. Problems: None.

IV. Solutions: None.

NUCLEAR REACTORS

DF270, NUCLEAR REACTORS

I. References:

Kaplan's, "Nuclear Physics," chapters 19, 20, 21; Jacobowitz's, Fundamentals of Nuclear Energy and Power Reactors," chapters 2, 3, 4, and 5; ST 3-155, para 2.9.

II. Discussion.

Definition: Reactor - a device in which a controlled nuclear chain reaction is taking place.

A. Physics of the Reactor.

1. Fission Reaction:

$$^{235}_{92}U + {}^{1}_{0}n \rightarrow 2\text{ ff} + 2.5\ {}^{1}_{0}n + 180\text{ Mev}$$

$$^{239}_{94}Pu + {}^{1}_{0}n \rightarrow 2\text{ ff} + 2.9\ {}^{1}_{0}n + 200\text{ Mev}$$

Energy Distrubution in Fission Reaction.

KE of ff	168 Mev
KE of ${}^{1}_{0}n$	5 Mev
KE γ rays	7 Mev
β from ff	7 Mev
γ from ff	6 Mev
Neutron cap γ's	7 Mev
	~ 200 Mev

2. Chain Reaction - occurs when fission reactions produce enough neutrons capable of causing fission to other nuclei.

$$\text{Multiplication factor: } K = \frac{\text{no of neutrons in 2d generation}}{\text{no of neutrons in 1st generation}}$$

Chain Reaction Characteristics:

Condition of Mass	Characteristics	Use
Subcritical, $K < 1$	Chain reactor decreases to zero	None
Critical, $K = 1$	Just sustains chain reaction at a constant number of fissions per unit time	Reactor
Supercritical, $K > 1$	Sustains increasing chain reaction	Weapons

Neutrons may be prevented from causing fission by:

a. Non-fission capture by uranium.

b. Non-fission capture by other materials.

c. Leakage; i.e., escape from the core.

B. Essential Features of a Nuclear Reactor.

1. Fuel: Material which will undergo fission in the reactor.

Fissionable Fuel: Materials which will undergo fission with thermal neutrons -

$^{233}_{92}U$, $^{235}_{92}U$, $^{239}_{94}Pu$

Fertile Fuels: Materials which, by the absorption of neutrons, become fissionable fuels -

$^{238}_{92}U$, $^{232}_{90}Th$

Production of fissionable fuel from fertile fuel:

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U$$

$$^{239}_{92}U \xrightarrow{23\text{ min}} ^{239}_{93}Np + ^{0}_{-1}e$$

$$^{239}_{93}Np \xrightarrow{2.3\text{ days}} ^{239}_{94}Pu + ^{0}_{-1}e$$

and

$$^{232}_{90}Th + ^{1}_{0}n \rightarrow ^{233}_{90}Th$$

$$^{233}_{90}Th \rightarrow ^{233}_{91}Pa + ^{0}_{-1}e$$

$$^{233}_{91}Pa \rightarrow ^{233}_{92}U + ^{0}_{-1}e$$

2. Moderator: Material used to slow fast neutrons to thermal velocities.

Slowing power of moderator: Ratio of slowing ability to absorbing ability - δ_s/δ_a.

H_2O - 65

D_2O - 4860

Be - 150

C - 120

3. Control Method: Means by which the rate of fission, and thereby the power output, of the reactor is regulated.

Methods of control:

Control rods (most common method)

Liquid control (primarily a safety control)

Removal or addition of fuel

Movement of a neutron reflector

4. Coolant - Material circulated around core for removal of heat.

Coolant types:

Liquid - (water)

Liquid Metal - (Sodium)

Gas - (CO_2)

Organic Compounds

Coolants - Desirable Characteristics:

Low melting point - remains fluid

High boiling points

Good thermal stability

Compatability with other parts

Low induced radioactivity

Low neutron absorption

Good radiation stability

Moderator power to suit reactor
(may serve double purpose)

5. Shielding - Material used to protect workers and equipment from radiation released during the fission process.

C. Classification of Reactors.

Type of arrangement of fuel:

Heterogeneous - moderator and fuel in regular arrangement.

Hemogenous - moderator and fuel mixed.

Moderator type:

Graphic

D_2O

Beryllium

Coolant used:

Water - pressurized
- boiling

Liquid metal

Gas

Organic material

Neutron energies:

Thermal (slow)

Intermediate

Fast

Purpose:

Research

Isotope production

Materials testing

Neutron source

Experimental

Production (breeding)

Power

Electrical

Propulsion

Stationary

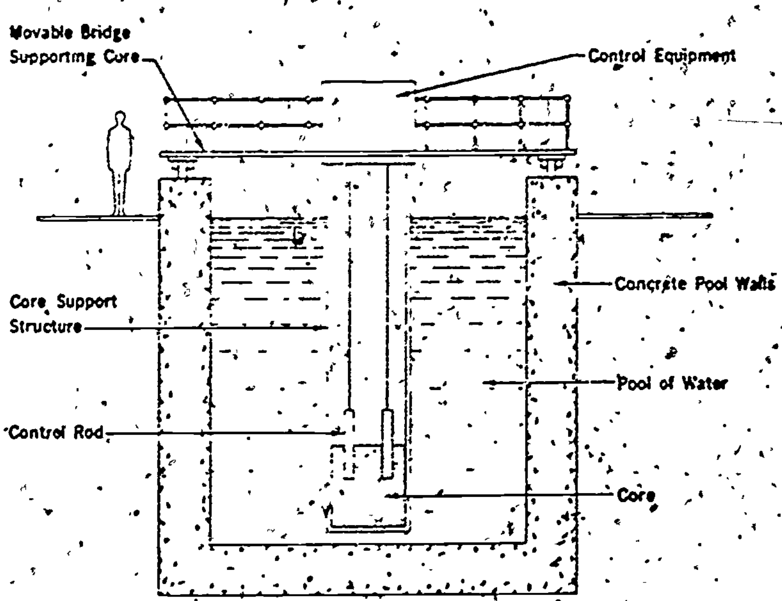
Mobile

Dual purpose (having two of the above uses)

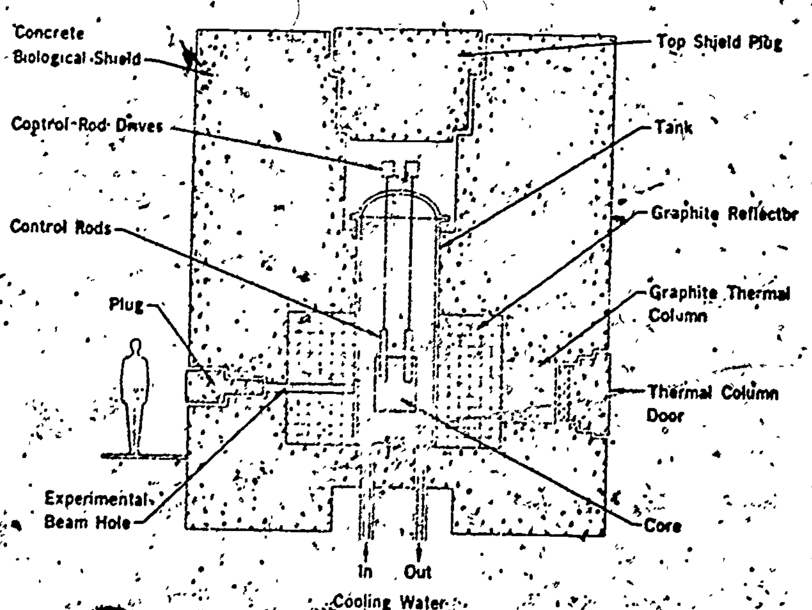
1. Types Discussed.

a. Research Reactors.

POOL REACTOR



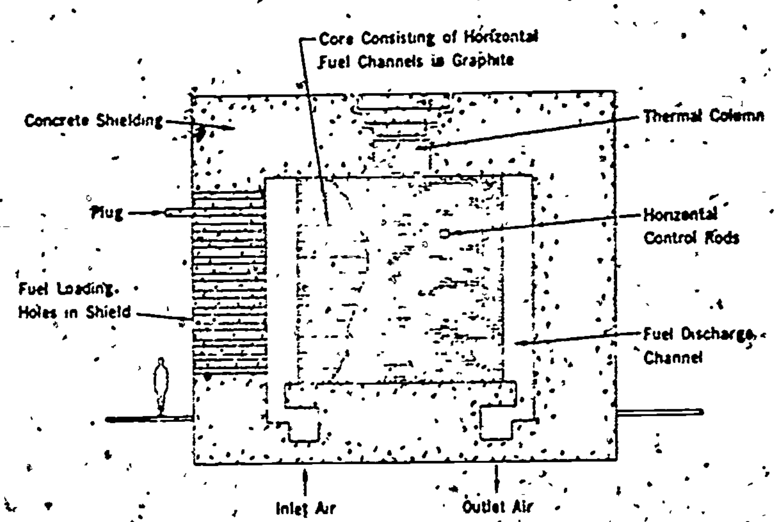
TANK REACTOR



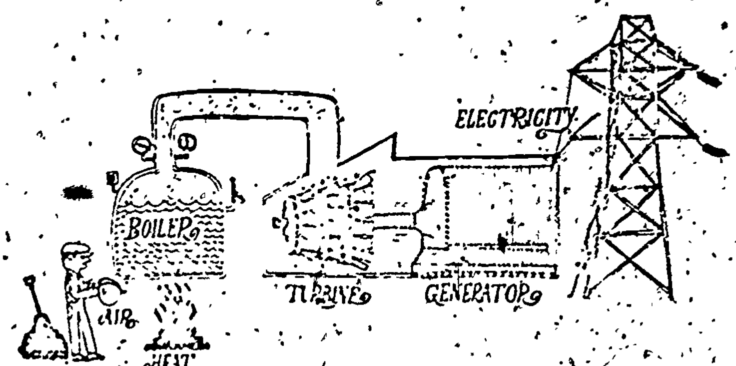
b. Breeder Reactors.

Graphite Pile Reactor.

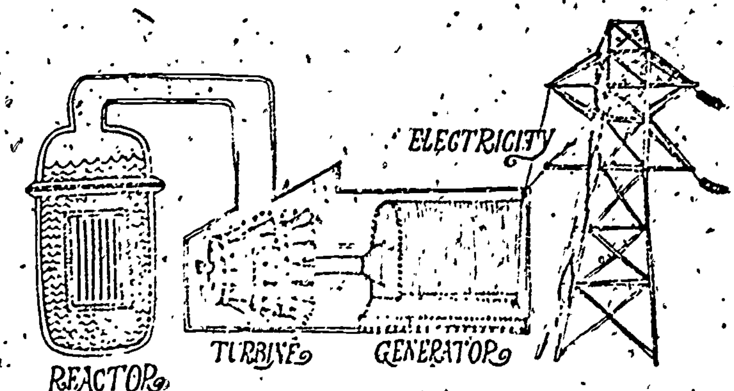
GRAPHIC REACTOR



COMPARISON OF CONVENTIONAL AND NUCLEAR POWER PLANTS



CONVENTIONAL POWER PRODUCTION

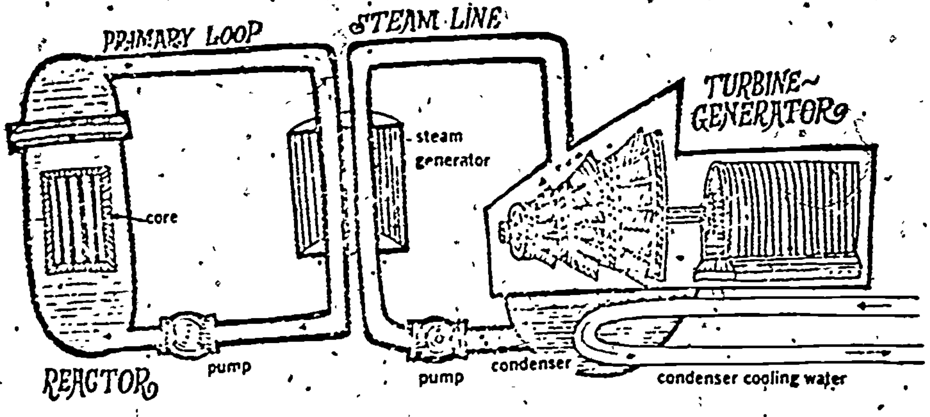


ATOMIC POWER PRODUCTION

c. Power Reactors.

(1) Pressurized water reactors.

PRESSURIZED WATER REACTOR



(a) Advantages.

Single fluid coolant, moderator, reflector.

Water cheap, available.

$^{16}_{7}N$ only radioactive problem.

Small critical mass needed.

Fission products contained.

Water technology known.

(b) Disadvantages.

High pressure in primary loop.

Poor thermodynamic efficiency.

Complex plumbing.

Corrosion problem.

Neutron economy poor.

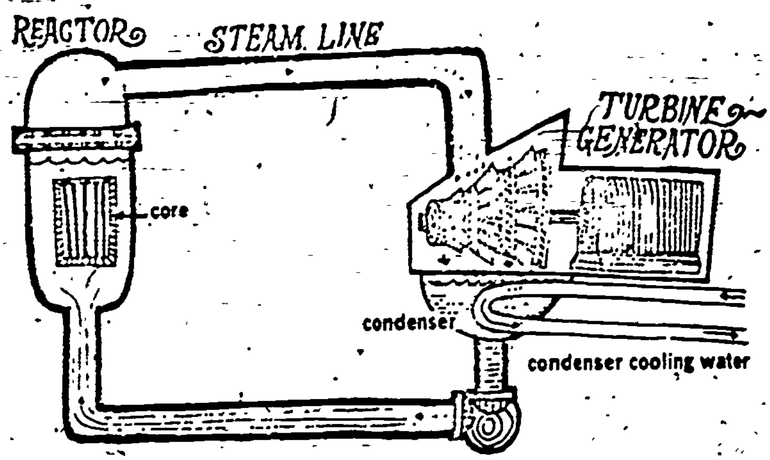
Shutdown for reloading.

Water reacts with U, Th and structural materials.

Fuel element design and use of control rods difficult.

(2) Boiling Water Reactors.

BOILING WATER REACTOR



(a) Advantages.

Same advantage as pressurized water reactor.

Single loop.

Lower pressure levels.

Lower temperature levels.

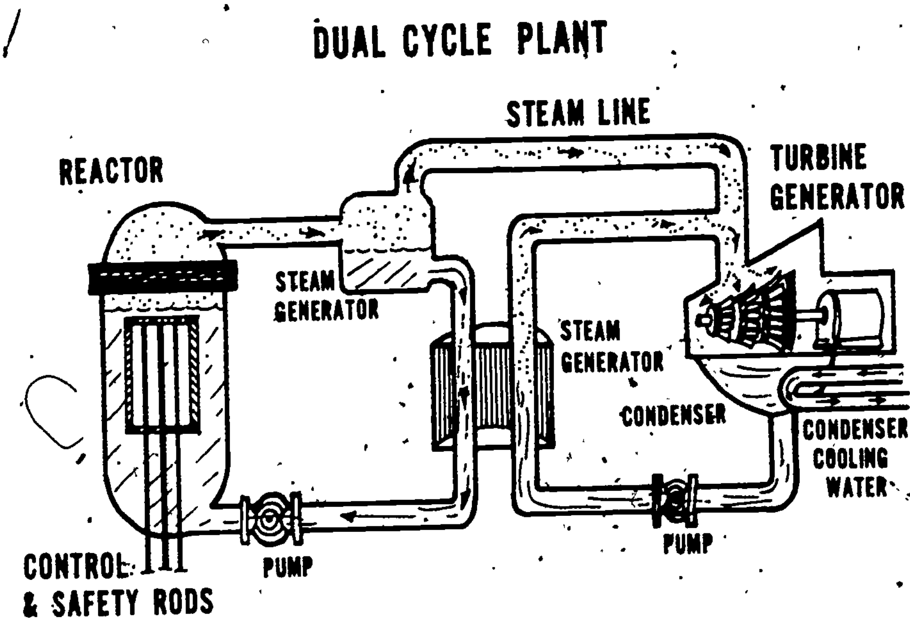
(b) Disadvantages.

Most disadvantages of pressurized water reactor.

Turbine may require shielding.

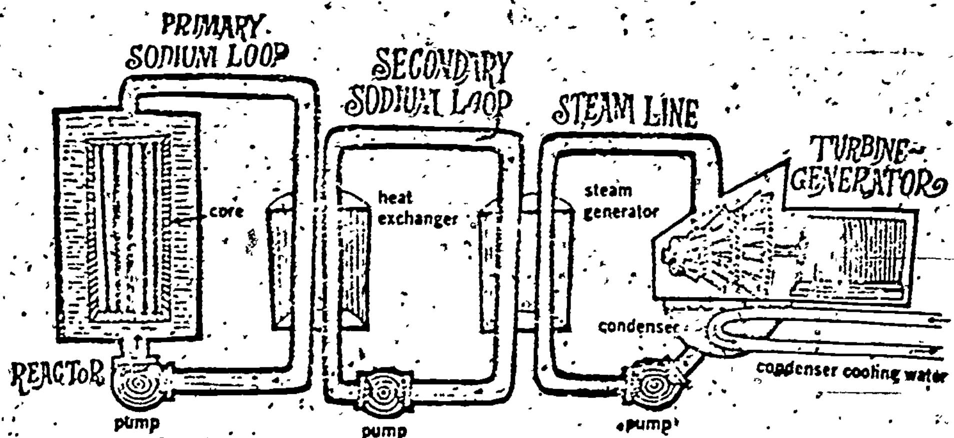
Reactivity lifetime short.

(3) Dual Cycle Plants.



(4) Sodium Cooled Reactors.

SODIUM COOLED REACTOR



(a) Advantages.

High temperature with low pressures.

Heat removal very efficient.

Super heater steam possible.

(b) Disadvantages.

Sodium reacts violently with water.

Large core needed.

Sodium becomes radioactive.

Intermediate loop needed.

Coolant will freeze at room temperature.

(5) Gas Cooled Reactors - use gas for coolant. (CO_2 and He are popular.)

(6) Liquid Fuel Reactors.

(a) Salt of uranium dissolved in H_2O.

(b) Uranium and bismuth mixed in molten state.

SOME NUCLEAR POWER PLANTS

NAME	LOCATION	TYPE	CAPACITY (KW)	STARTUP
Shippingport Atomic Power Station	Shippingport, PA	Pressurized water	100,000	1957
Dresden Nuclear Power Station	Morris, ILL	Boiling water	200,000	1959
Yankee Atomic Electric Station	Rowe, Mass	Pressurized water	175,000	1960
Indian Point Station	Indian Point NY	Pressurized water	255,000	1962
Hallam Nuclear Power Facility	Hallam, Neb	Sodium-graphite	75,000	1962
Humboldt Bay Power Plant	Eureka, CA	Boiling water	48,500	1963
Big Rock Nuclear Power Plant	Charlevoix, Mich	Boiling water	72,800	1962
Enrico Fermi Atomic Power Plant	Lagoona Beach, Mich	Fast breeder	60,900	1963
Pathfinder Atomic Power Plant	Sioux Falls, SD	Boiling water with integral nuclear superheating	58,500	1964
Peach Bottom Atomic Power Station	Peach Bottom, PA	High temperature gas-cooled	40,000	1965
La Crosse Boiling Water Reactor	Genoa, Wisc	Boiling water	50,000	1965

(Continued)

NAME	LOCATION	TYPE	CAPACITY (KW)	STARTUP
San Onofre Nuclear Generating Station	San Clemente, CA	Pressurized water	375,000	1966
New Production Reactor and Power Plant	Richland, Wash	Graphic, dual purpose	800,000	1966
Malibu Nuclear Plant	Corral Canyon, CA	Pressurized water	462,000	1968
Connecticut Yankee Nuclear Power Station	Haddam-Neck, Conn	Pressurized water	462,000	1967
Oyster Creek Station	Oyster Creek, NJ	Boiling water	515,000	1967
Nine Mile Point Plant	Oswego, NY	Boiling water	500,000	1968
Elk River Reactor	Elk River, Minn	Boiling water	23,000	1962
Carolinas-Virginia Tube Reactor	Parr, SC	Pressure tube, heavy water	17,000	1963
Piqua Nuclear Power Facility	Piqua, Ohio	Organic cooled and moderated	11,400	1963
Boiling Reactor Nuclear Superheat Project	Punta Higuera, Puerto Rico	Boiling water, integral nuclear superheat	16,500	1964

3. Military Reactors.

Nomenclature on Military Reactors

1st Letter - degree of mobility
S - stationary
P - portable
M - mobile

2d Letter - Power range

L - low	100 - 1000 kw	
M - medium	1000 - 10,000 kw	
H - high	10,000 or more kw	

Arabic numeral indicates order of initiation of plants with same first two letters.

Capital letter following numerical indicates order of initiation of field plants of same type.

Some Military Reactors in Operation

SM-1 (Ft Belvoir, VA)	Prototype and training plant	AEC and Army
SM-1A (Ft Greely, AL)	Base power supply	Army
PM-3A (McMurdo Sound, ART)	Power supply for base at remote location	Navy
MH-1A (Mobile)	Floating nuclear power plant to supply power for off-shore to land base	AEC and DOD
ML-1 (Mobile)	Trailer mounted prototype for field use	AEC and Army

D. Reactor Safety.

1. Basic Safety Principle:

a. Prevent accidents.

<u>Prevention</u>

Core and design

Natural laws used to advantage

Automatic safety controls

Trained personnel

b. Contain radioactivity in the event of an accident.

<u>Containment</u>

1st Defense	Fuel cladding
2d Defense	Location in remote areas
3d Defense	Containment shell

2. Everyday Reactor Safety.

a. Worker.

Disposal of burned fuel

Check for contaminants in coolant and ventilation systems

Monitoring throughout plant.

Radiation exposure levels observed

b. Public.

Discharges from plant monitored (i.e., air, water, sewage)

Areas surrounding plant monitored

Notes:

III. Handouts: None

IV. Problems: None

V. Solutions: None

BETA PARTICLE CONSIDERATIONS

DF290, BETA PARTICLE CONSIDERATIONS

I. Discussion.

Beta particles are readily absorbed in solid media. As a result of this absorption, or attenuation, high energy electromagnetic radiation is produced. Like gamma radiation, it is hazardous and must be considered when handling and storing beta emitting radioisotopes.

Beta radiation is produced by the decay of a nuclear particle. Beta particles may be either negatively or positively charged, depending on whether a neutron or proton decays.

$$^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}e + \nu + Q \quad (\beta^{+} \text{ decay})$$

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \overline{\nu} + Q \quad (\beta^{-} \text{ decay})$$

We will consider each type of beta decay separately.

A. β^{+} Decay.

A positively charged beta particle results from the decay of a proton. As the β^{+} particle loses its kinetic energy and becomes thermalized, it will undergo an annihilation reaction with an electron. The process of electron-positron annihilation is called pair annihilation and results in the production of two photons, each with 0.511 Mev energy. The shielding material which stops the beta radiation acts as a source of 0.511 Mev electromagnetic radiation. This e-m radiation is as hazardous as gamma radiation and must be shielded against.

In order to calculate the total amount of shielding necessary to attenuate both the beta radiation and the electromagnetic radiation, the following procedure will be used.

1. Determine the maximum beta energy ($E_{\beta max}$) using the Table of Isotopes, Pam 25.

2. Determine the range (R) of this maximum beta particle using the Range Energy Curve on page 123 of Pam 25.

3. Determine thickness (X_{β}) of shielding material required to stop the most energetic beta particle.

$$X_{\beta} = \frac{R}{\rho_{\text{absorber}}} \quad (\rho \text{ values listed on pages 65-66, Pam 25})$$

4. Determine the source strength of the electromagnetic radiation produced by the electron-positron annihilation.

$$S_{ann} = (2)(0.56)nCE \text{ (where } E = 0.511 \text{ Mev)}. \therefore S_{ann} = 0.572\,nC$$

NOTE: Two photons, each with an energy of 0.511 Mev, are produced in pair annihilation. Therefore, we must consider shielding for two photons for each positron given off by the source. This is why the source strength formula is multiplied by 2.

The contribution of each beta transition must be considered.

5. Determine an unshielded dose rate at a desired location.

$$R_o = \frac{S}{d^2}$$

where d is distance measured from edge of beta shield.

6. Determine the half-thickness ($X_{\frac{1}{2}}$) of the shield. Use table (pages 137-139, Pam 25) to determine μ/ρ (enter with E = 0.511), then

$$\mu = \frac{\mu}{\rho} \times \rho, \text{absorber}$$

and

$$X_{\frac{1}{2}} = \frac{0.693}{\mu}$$

7. Solve shielding problem using 2^n method with:

R_o from Step 5.

$X_{\frac{1}{2}}$ from Step 6.

Either X or R must be given.

Solve using 2^n Tables.

The total thickness of material necessary will be a combination of the beta shield (X_β) and the e-m shield (from Step 7).

B. β^- Decay.

A β^- particle is a high speed electron resulting from the decay of a neutron. This high speed electron may interact with matter in three general ways:

1. Collision with an outer electron. The high speed electrons may collide with one of the outer electrons of an atom within the target. This orbital electron will be knocked from the atom resulting in ionization. The energy absorbed by ionization is given off as heat and light. This interaction will not produce electromagnetic radiation and is of no significance for this class.

2. Collision with an inner electron. The electron may penetrate the outer electron cloud of a target atom and collide with one of the electrons in an inner shell. This inner electron will be knocked from the atom and an electron from an outer shell will fall into its place. Energy absorbed in the process of knocking out these internal electrons is given off in the form of X-rays which are characteristic of the absorbing material. This interaction will not produce significantly harmful radiation.

3. Attraction to the nucleus. If a high speed electron penetrates the electron cloud without colliding with one of the electrons, it experiences a coulombic attraction toward the nucleus. This attraction slows down the high speed electron or causes it to be deviated from its path, causing an overall linear deceleration, reducing the kinetic energy of the electron. The energy lost is given off in the form of electromagnetic radiation which differs from gamma radiation in origin only and is known as **bremsstrahlung.** The word is of German origin (brem, to apply the brake; strahlung, radiation). Bremsstrahlung is sometimes called braking radiation.

If an electron has a kinetic energy of less than 0.1 Mev, it is not energetic enough to penetrate the outer electron cloud of an atom. Therefore, only electrons or beta particles of kinetic energy greater than 0.1 Mev can cause **bremsstrahlung.**

Bremsstrahlung has a continuous spectrum. Not all electrons are slowed to the same degree, and therefore, the kinetic energy lost and energy of electromagnetic radiation given off varies with the conditions. The energy of the emitted radiation depends on the Z number of the absorber, the original energy of the high speed electron (or beta particle) and the proximity of the high speed electron to the nucleus of the absorber. The larger the Z number of the absorber, the greater is the attraction of the high speed electron to the absorber nucleus, and the more energetic is the bremsstrahlung emitted due to the slowing down of the electron.

The maximum energy of the bremsstrahlung resulting from the attenuation of an electron or beta particle is the energy of the electron or beta particle which is attenuated. The absorption of low energy betas cannot produce high energy bremsstrahlung. The closer the electron passes to the nucleus, the greater the attraction to the nucleus, and the more energetic the resulting bremsstrahlung.

Of all beta particles or high speed electrons which are absorbed by a medium, only a small fraction is attenuated to result in bremsstrahlung. This fraction may be determined using the expression:

$$f = 3.3 \times 10^{-4} Z E_{\beta}$$

where f is the fraction of particles absorbed to give off bremsstrahlung.

Z is the Z number of the absorber

E_{β} is the maximum energy of the beta given off in a specific nuclear transition.

Since the resultant radiation is like gamma radiation, its source strength may be calculated using the equation:

$$S = 0.56\ n C_b E_{\beta}$$

where S = source strength in rhm.

n = fraction of times particles undergo disintegration to yield beta with maximum energy E_{β}.

E_{β} = maximum energy of the beta particle for each nuclear transition.

C_b = number of curies of beta emitter resulting in bremsstrahlung.

or $C_b = Cf$

where c is total number of curies of beta emitter.

Therefore: $S = 0.56\ n C E_{\beta} f$

Substituting for f: $S = 1.85 \times 10^{-4} n (E_{\beta})^2 C Z$

If the beta emitter disintegrates by more than one route, the contribution of each beta decay must be considered. For radioisotopes which are both beta and gamma emitters, the source strength contribution of both the bremsstrahlung and gamma must be considered. Several conventions may be established to make the source strength calculations less tedious.

1. When the maximum energy of the beta particle is less than 0.1 Mev, any bremsstrahlung produced is insignificant.

2. Bremsstrahlung produced by betas of energy greater than 0.1 Mev is significant.

3. Bremsstrahlung produced by positrons (β^+) will be considered using the same rules as for beta particles.

In order to produce bremsstrahlung, beta particles must be absorbed. Therefore, an important part of a calculation of bremsstrahlung is the determination of the thickness of shield required to stop the beta particles. This is determined by finding the maximum energy of the beta particles emitted (E_β); its range, using Sargent's rule, Feather's rule (page 29, Pam 25), or graphs (page 123, Pam 25); and finally, the thickness of shielding material required to stop this most energetic beta.

Once the bremsstrahlung source strength has been determined, the shielding required to bring the dose rate to a given value at a given point may be determined in the same manner as with gamma sources using Total Mass Attenuation Coefficient Tables. When entering this table, one uses an energy for bremsstrahlung of one-half of the maximum beta particle energy $\frac{E_\beta}{2}$.

If the bremsstrahlung is associated with gamma, the mass attenuation tables are entered with one-half the maximum beta energy or the highest gamma energy, whichever is the larger.

A procedure which may be used in bremsstrahlung calculations is:

1. Determine the maximum beta energy using the Table of Isotopes, Pam 25.

2. Determine the range of this beta (R) using Feather's rule, Sargent's rule or Beta Particle Range Energy Curve (page 123, Pam 25).

3. Determine thickness of shielding material required to stop the most energetic beta ($X_\beta = \frac{R}{\rho}$, ρ values are listed on pages 65-66, Pam 25).

4. Determine the source strength of **bremsstrahlung** produced during stopping of beta.

$$S = 1.85 \times 10^{-4} \, nCZ(E_{\beta})^2$$

Z values are listed on page 65, 68, or page just before the Table of Isotopes in Pam 25.

The contribution of each beta transition must be considered.

5. Determine an unshielded dose rate at a desired location.

$$R_o = \frac{S}{d^2}$$

6. Determine half-thickness ($X_{\frac{1}{2}}$) of shield using $\frac{E_{\beta max}}{2}$ of emitted beta radiation. Use table (page 137-139) to determine μ/ρ corresponding to $\frac{E_{\beta max}}{2}$. Then $X_{\frac{1}{2}} = \frac{0.693}{\mu}$ where $\mu = \mu/\rho \times \rho$.

7. Solve shielding problem using 2^n method with

$$R_o = \frac{S}{d^2} \quad \text{(From Step 5)}$$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} \quad \text{(From Step 6)}$$

Either R or X must be given.

Solve for unknown using 2^n tables.

NOTE: If the source emits beta, positrons and gamma, then the half-thickness will be determined by

$\frac{E_{\beta max}}{2}$, $E_{\gamma max}$, or 0.511 Mev, which ever is greater; and total source strength ($S_T = S_{Brem} + S_{\gamma} + S_{ann}$) must be used to calculate the unshielded dose rate, R_o.

8. Determine $X_{\frac{1}{2}}$ of shield using either $\frac{E_{\beta max}}{2}$, or $E_{\gamma max}$, or 0.511 Mev, whichever is greater. Same as Step 6.

9. Solve shielding problem using 2^n method, with

$$R_o = \frac{S_T}{d^2} \qquad \text{(From Step 5)}$$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} \qquad \text{(From Step 8)}$$

Either R or X must be given.

Solve for unknown using 2^n tables.

The following procedures will be used for energy determinations to solve bremsstrahlung problems.

1. Bremsstrahlung cannot be calculated for an isotope unless it has a decay scheme in Table II, Table of Isotopes, Pam 25. (Decay schemes not listed in Pam 25 can be found in the book "Table of Isotopes," by C. M. Lederer, J. M. Hollander, and I. Perlman, 6th Edition, published by John Wiley and Son, Inc., New York, 1967.

2. The beta energies will be taken from the tabulated data in Table II, Table of Isotopes, Pam 25.

3. The percentages of each of the beta energies will be obtained from the decay scheme in Table II, Table of Isotopes, Pam 25. If no percentages are given in the decay scheme, then use those given in tabulated data, Table II, Table of Isotopes, Pam 25.

4. Neglect all decays which occur less than 3% of the time.

5. Gamma percentages and energies will be obtained from the decay scheme (use total drop) in Table II, Table of Isotopes, Pam 25. If no percentages are given in the decay scheme, then use the percentages given in tabulated data, Table II, Table of Isotopes, Pam 25, for the beta particle which decayed to that gamma energy level.

C. Bremsstrahlung Radiation.

According to the classical electromagnetic theory, any charged particle which undergoes an acceleration emits radiant energy. The acceleration of a particle is inversely proportional to its mass. As we have already discussed in β^- considerations, an electron in the Coulomb field of a nucleus can experience a large acceleration by virtue of its small mass.

The bremsstrahlung effect is charge independent. **Positively charged particles will produce braking radiation. Therefore, we consider bremsstrahlung and annihilation radiation when dealing with positrons.** Bremsstrahlung does not become important in the energy loss of heavy particles until the Bev energy range is reached. At these energies, the particles can approach the scattering nuclei more closely and thereby experience larger forces which compensate for the increased mass. However, heavy particles can only be accelerated up to the Bev energy range with the largest particle accelerators. Bremsstrahlung will not be a problem with heavy particles produced by normal radioactive decay.

II. Lesson Objectives and Notes:

A. Shielding of beta particles.

B. β^+ decay.

C. β^- decay.

D. Bremsstrahlung computations.

III. Handouts:

Vu-Graph Material

CHARACTERISTICS OF γ, X-RAY, AND BREMSSTRAHLUNG

Type	Energy Spectrum	Source	Characteristics
Gamma	Discrete	Nucleus	Of element nucleus
Bremsstrahlung	Spectral	Fast charged particle	Of particle velocity and charge of nucleus
X-ray	Discrete	Orbital electron	Of element electron structure

IV. Problems.

1. What thickness of lucite is required to stop the beta particles from a one-curie source of ^{32}P? Calculate the bremsstrahlung dose rate at 20 cm produced by using this shield. Density of lucite is 1.2 gm/cm^3 and its Z number = 3.6.

2. How much lead is required in Problem 1, in addition to the lucite, to reduce the dose rate reading to 5 mrad/hr at 20 cm?

3. What thickness of lead is required to stop the beta particles and reduce the bremsstrahlung dose reading to 5 mrad/hr at 20 cm from a one-curie source of ^{32}P? (This problem is similar to Problem 1 and 2, but lead is used instead of lucite to stop the beta particles.)

4. You are designing an iron container for a ^{22}Na salt used in medical research. A maximum of 2 curies of ^{22}Na will be in the container at any one time. How thick must the container wall be to reduce the dose rate to 1 mrad/hr at 1 meter from the outside surface of the container?

5. You have received a ^{63}Ni beta check source. Compute the thickness of lead shielding necessary to reduce the dose rate to one mrad/hr at 1 meter from the source. The source has an activity of 5 curies.

6. One hundred millicuries of ^{198}Au is used for each decontamination exercise conducted in Scaler Lab T, USAOC&S. ^{198}Au is shipped in a polyethylene container shielded with lead. The density of polyethylene is 0.92 gm/cm^3 and its $Z = 2.667$.

a. How much polyethylene is required to stop all beta radiation?

6. b. How much lead is necessary to reduce the dose rate to 10 mrad/hr at 1 meter from the source?

7. a. What thickness of Al will stop the beta from a 25 mCi source of ^{90}Sr - ^{90}Y (pure beta emitter)?

b. What will be the dose rate at 15 cm from the source in part a? In calculating source strength, assume 25 mCi of ^{90}Sr and 25 mCi of ^{90}Y.

7. c. What will be the dose rate at 15 cm after inserting a 2.2 cm lead shield in addition to the aluminum? (This situation corresponds closely to that in the TS-784( )/PD.)

______

d. How many hours per week can a military operator work 15 cm from this source? (MPE = 300 mrad/week)

8. How much lead is necessary to ship 5 curies of ^{85}Kr and not exceed 10 mrad/hr 1 meter from the source?

9. The calibrator AN/UDM-1A uses a ^{137}Cs source with an activity of 120 curies. How much lead is required to reduce the dose rate to 10 mrad/hr at 1 meter?

V. Solutions.

1. Given ^{32}P source; calculate R_{brem} at 20 cm.

$C = 1Ci$ $\rho_{lucite} = 1.2\ g/cm^3$

$d = 20\ cm$ $Z_{lucite} = 3.6$

(1) $E_\beta = 1.708$ (page 383, Pam 25) (100%)

(2) Range = 780 mg/cm^2 (page 123, Pam 25)

$\rho_{lucite} = 1.2\ g/cm^3 = 1200\ mg/cm^3$

(3) $X = \frac{R}{\rho} = \frac{780}{1200}$

$X = \underline{0.65\ cm\ lucite}$

(4) $S_{brem} = 1.85 \times 10^{-4} CE_\beta{}^2 Zn$

$= 1.85 \times 10^{-4}(1)(1.708)^2(3.6)(1)$

$= 1.943 \times 10^{-3}$ rhm = 1.943 mrhm

(5) $R = \frac{S}{d^2}$

$= \frac{1.943}{(0.2)^2} = \frac{1.943}{0.04}$

$=$ 48.6 mrad/hr - ANSWER

2. Given ^{32}P source; calculate thickness of lead required to reduce R to 5 mrad/hr at 20 cm.

$C = 1Ci$ $\rho_{lead} = 11.35\ g/cm^3$

$d = 20\ cm$ $R_o = 48.6$ mrad/hr (from Problem 1)

$\frac{E_{\beta max}}{2} = \frac{1.708}{2} = 0.854$ Mev

2. (Cont.)

$$
200\left[\begin{array}{lll} 54\left[\begin{array}{l}800\\854\end{array}\right. & \begin{array}{l}0.0885\\ \mu/\rho\end{array} & \Big] X \\ 1000 & 0.0708 & \end{array}\right] 0.0177
$$

Kev	cm^2/g
800	0.0885
854	μ/ρ
1000	0.0708

$$\frac{54}{200} = \frac{X}{0.0177}$$

$$X = 0.0048$$

$$\mu/\rho = 0.0885 - 0.0048 = 0.0837\ cm^2/g$$

$\rho_{Pb} = 11.35\ g/cm^3$ (page 65, Pam 25)

$$\mu = (\mu/\rho)(\rho)$$

$$\mu = (0.0837)(11.35)$$

$$\mu = 0.95\ cm^{-1}$$

(6) $X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{0.95}$

$$X_{\frac{1}{2}} = 0.729\ cm$$

(7) $2^n = \frac{R_o}{R} = \frac{48.6}{5} = 9.72$

$$n = 3.3$$

$X = nX_{\frac{1}{2}} = (3.3)(0.729) = \underline{\underline{2.41\ cm\ of\ lead}}$ - ANSWER.

3. Given ^{32}P source; calculate thickness of lead to shield β and Bremsstrahlung to $R = 5$ mrad/hr at 20 cm.

(1) $E_\beta = 1.708$ (page 383, Pam 25)

(2) $R = 780\ mg/cm^2$ (page 123, Pam 25)

(3) $X = \frac{R}{\rho}$ where $\rho_{lead} = 11.35\ g/cm^3$ (page 65, Pam 25)

$$= \frac{780}{11350}$$

$$= \underline{\underline{6.87 \times 10^{-2}\ cm\ Pb}}$$

(4) $S_{brem} = 1.85 \times 10^{-4}\ CE_{\beta}^{2}\ Zn$

$= 1.85 \times 10^{-4}(1)(1.708)^{2}(82)(1)$

$= 4.425 \times 10^{-2}$ rhm $=$ 44.25 mrhm

(5) $R_{o} = \frac{S}{d^2} = \frac{44.25}{(0.2)^2} = \frac{44.25}{0.04} = 1106$ mrad/hr

(6) $X_{\frac{1}{2}} \doteq \frac{0.693}{\mu} = 0.729$ cm (from Problem 2)

(7) $2^n = \frac{R_o}{R} = \frac{1106}{5} \doteq 221$

$n = 7.9$

$X \doteq nX_{\frac{1}{2}} = (7.9)(0.729) = 5.76$ cm of lead

Total Thickness = $\underline{\underline{5.83 \text{ cm of lead}}}$ - ANSWER

NOTE: This is over twice as much lead as required if we use lucite to shield beta (see Problem 2). A lead shield is not necessarily the best shield for all types of radiation.

4. Given ^{22}Na source, β^+, and γ decay; calculate thickness of iron needed to reduce R to 1 mrad/hr at 1 meter.

(1) $E_{\beta^+} = 0.545$ (from page 382, Pam 25) (90%)

$E_\gamma = 1.2746$ (100%)

(2) $R = 180 \text{ mg/cm}^2$ (from page 123, Pam 25)

(3) $X = \frac{R}{\rho}$ where $\rho = 7.86 \text{ g/cm}^3$ (page 65, Pam 25)

$= \frac{180}{7860} = 0.0229$ cm of iron

(4) $S_{brem} = 1/85 \times 10^{-4}\ nCZE_\beta^2$

$= 1.85 \times 10^{-4}\ (0.9)(2)(26)(0.545)^2$

$= 2.57 \times 10^{-3}$ rhm $= 2.57$ mrhm

$S_\gamma = 0.56\ nCE$

$= 0.56\ (1)(2)(1.2746)$

$= 1.428$ rhm $= 1428$ mrhm

$S_{ann} = 0.572\ nC$

$= 0.572\ (0.9)(2)$

$= 1.029$ rhm $= 1029$ mrhm

$$S_T = S_b + S_\gamma + S_a$$

$$= 2.57 + 1428 + 1029 \text{ mrhm}$$

$$= 2460 \text{ mrhm}$$

(5) $R = \frac{S}{d^2} = \frac{2460}{1^2} = 2460 \text{ rad/hr}$

(6) Using 1.2746 Mev and $\rho = 7.86 \text{ gm/cm}^3$

$$0.5\left[\begin{array}{ll} 0.2746 \left[\begin{array}{ll} 0.1 & 0.0599 \\ 1.2746 & \mu/\rho \end{array}\right] X & \\ & \\ 1.5 & 0.0488 \end{array}\right]0.0111$$

$$\frac{0.2746}{0.5} = \frac{X}{0.0111}$$

$$X = 0.0061$$

$$\mu/\rho = 0.0599 - 0.0061$$

$$= 0.0538$$

$$\mu = \mu/\rho \times \rho = 0.0538 \times 7.86$$

$$= 0.423 \text{ cm}^{-1}$$

$$X_{\frac{1}{2}} = \frac{0.693}{0.423} = 1.64 \text{ cm}$$

(7) $2^n = \frac{R_o}{R} = \frac{2460}{1} = 2460$

$$n = 11.3$$

$$X = nX_{\frac{1}{2}} = (11.3)(1.64) = 18.53 \text{ cm}$$

$$X_{total} = X_\beta + X_{Ss} = 0.0229 + 18.53$$

$= \underline{\underline{18.55 \text{ cm of iron}}}$ - ANSWER

5. Given ^{63}Ni source; compute thickness of lead necessary to reduce R to 1 mrad/hr at 1 meter.

(1) E_β = 0.067 Mev (100%) (page 389, Pam 25)

(2) R = 6.8 mg/cm^2 (page 123, Pam 25)

(3) $X = \frac{R}{\rho}$ where $\rho = 11.35\ g/cm^3$ (page 65, Pam 25)

$X = \frac{6.8}{11350} = \underline{\underline{0.599 \times 10^{-3}\ cm}}$ - ANSWER

NOTE:

(a) Since the maximum energy of the beta particle is less than 0.1 Mev, it does not possess enough energy to produce bremsstrahlung. Therefore, we only have to shield out the beta particles.

(b) It is also obvious that lead is not a practicable shield for this source. In fact, air has a density of $1.293 \times 10^{-3}\ g/cm^3$ (from page 66, Pam 25). Therefore,

$X_{air} = \frac{6.8}{1.293} = 5.26$ cm

which means that air is sufficient to stop all the beta particles emitted, and other shielding is not necessary to meet the requirements. This does not mean the source can be handled.

6. Given ^{198}Au source.

a. Find: Thickness of polyethylene required to stop beta radiation.

(1) E_β = 0.961 Mev (99%) (page 405, Pam 25)

(2) R = 380 mg/cm^2 (page 123, Pam 25)

(3) $X = \frac{R}{\rho}$ where $\rho = 0.92\ g/cm^3$

$\therefore X = \frac{380}{920} = \underline{\underline{0.413\ cm\ of\ polyethylene}}$ - ANSWER

b. Find: Thickness of lead to give R = 10 mrad/hr at 1 meter.

(1) $S_\gamma = 0.56nCE$

$= 0.56(0.99)(0.1)(0.4118) = 0.0228$ rhm $= 22.8$ mrhm

$S_{brem} = 1.85 \times 10^{-4}\ nCZE_\beta^2$

$= 1.85 \times 10^{-4}\ (0.99)(0.1)(2.667)(0.961)^2$

$= 4.51 \times 10^{-5}$ rhm $= 0.0451$ mrhm

$S_T = S_\gamma + S_b$

$= 22.8 + 0.0451$ mrhm

$= 22.8451$ mrhm $= 22.85$ mrhm

(2) $R = \frac{S}{d^2} = \frac{22.85 \text{ mrhm}}{(1)^2} = 22.85$ mrad/hr

(3) Use $\frac{E_{\beta max}}{2} = 0.4805$ Mev

$\mu/\rho = 0.175$ gm/cm^2

$\mu = \mu/\rho \times \rho = 0.175 \times 11.35 = 1.986$ cm^{-1}

$X_{\frac{1}{2}} = \frac{0.693}{1.986} = 0.349$

(4) $2^n = \frac{R_o}{R} = \frac{22.85}{10} = 2.285$

$\therefore n = 1.2$

$X = nX_{\frac{1}{2}} = (1.2)(0.349) = \underline{\underline{0.419 \text{ cm}}}$ - ANSWER

7. Given $^{90}Sr - {}^{90}Y$ source.

a. Calculate thickness of Al required to stop β.

(1) $E_{\beta max}$ $^{90}Sr - {}^{90}Y = 2.268$ Mev (page 392, Pam 25)

(2) Range $= 1100\ mg/cm^2$ (page 123, Pam 25)

$\rho_{Al} = 2.699\ gm/cm^3 = 2699\ mg/cm^3$ (page 65, Pam 25)

(3) $X = \frac{R}{\rho}$

$= \frac{1100}{2699}$

$= \underline{\underline{0.408\ cm\ Al}}$ - ANSWER

b. Calculate the total source strength assuming 25 mCi of each.

(4) $S_{brem} = 1.85 \times 10^{-4}\ CZ\Sigma n.E_\beta^2$

$= (1.85 \times 10^{-4})(25\ mCi)(13)\ [(1)(0.546)^2 + (0.99)(2.268)^2]$

$= 0.324$ mrhm

(5) $R = \frac{S_T}{d^2} = \frac{0.324}{(0.15)^2} = \frac{0.324}{0.0225} = \underline{\underline{14.4\ mrad/hr}}$ - ANSWER

c. $\frac{E_{\beta max}}{2} = \frac{2.268}{2} = 1.134$ Mev

$\mu/\rho = 0.0657\ cm^2g$

$\rho_{lead} = 11.35\ g/cm^3$ (page 65, Pam 25)

$\mu = \mu/\rho \times \rho$

$= (0.0657)(11.35)$

$= 0.746\ cm^{-1}$

(6) $X_{\frac{1}{2}} = \frac{0.693}{\mu}$

$= \frac{0.693}{0.746} = 0.929$ cm

(7) $R = \frac{R_o}{2^n}$

$n = \frac{X}{X_{\frac{1}{2}}} = \frac{2.2}{0.929} = 2.37$

$2^n = 4.95$

$R = \frac{14.4}{4.95} = \underline{\underline{2.91 \text{ mrad/hr}}}$ - ANSWER

d. $D = 300$ mrad $\qquad R = 2.91$ mrad/hr

$t = ?$

$t = \frac{D}{R} = \frac{300 \text{ mrad}}{2.91 \text{ mrad/hr}} = 103$ hours

8. Given ^{85}Kr source; calculate lead shielding needed to reduce R to 10 mrad/hr at 1 meter.

(1) $E_{\beta max} = 0.67$ Mev (99.6%)

(2) $R = 235$ mg/cm^3 $\qquad \rho_{Pb} = 11.35$ g/cm^3

(3) $X_\beta = \frac{R}{\rho} = \frac{235}{11350} = 0.0207$ cm of lead

(4) $S_{brem} = 1.85 \times 10^{-4} nCZE_\beta^2$

$= (1.85 \times 10^{-4})(0.996)(5)(82)(0.67)^2$

$= 0.0339$ rhm $= 33.9$ mrhm

(5) $R_o = \frac{S}{d^2} = \frac{33.9}{(1)^2} = 33.9$ mrad/hr

(6) $X_{\frac{1}{2}} = \frac{0.693}{\mu}$

$\frac{E_{\beta max}}{2} = \frac{0.67}{2} = 0.335$ Mev

$\mu/\rho = 0.3435$ cm^2/g

$\mu = (0.3435)(11.35) = 3.9$ cm^{-1}

$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{3.9}$ cm^{-1} $= 0.178$ cm

(7) $2^n = \frac{R_o}{R} = \frac{33.9 \text{ mrad/hr}}{10 \text{ mrad/hr}} = 3.39$

$n = 1.8$

$X = nX_{\frac{1}{2}} = (1.8)(0.178) = 0.32 \text{ cm}$

(8) $X_T = 0.0207 \text{ cm} + 0.32 \text{ cm} = 0.3407 \text{ cm}$ or

0.341 cm of lead - ANSWER

9. Given ^{137}Cs source; calculate thickness of lead to reduce R to 10 mrad/hr at 1 meter.

(1) $E_{\beta max} = 1.176$ (page 399, Pam 25)

(2) $R = 490 \text{ mg/cm}^2$

(3) $X = \frac{R}{\rho} = \frac{490}{11350} = 0.0432$ cm of Pb

(4) $S_{brem} = 1.85 \times 10^{-4} \, nCZ(E_\beta)^2$

$= (1.85 \times 10^{-4})(120)(82) [(0.935)(0.514)^2 + (0.065)(1.176)^2]$

$= 0.6133$ rhm

$S_\gamma = 0.56 \, nCE$

$= (0.56)(120)(0.935)(0.6616) = 41.57$ rhm

$S_{total} = S_{brem} + S_\gamma = 42.18$ rhm

(5) $R_o = \frac{S_{total}}{d^2} = \frac{42.18}{1^2} = 42.18$ rad/hr

(6) Find $X_{\frac{1}{2}}$

Use $E_\gamma = 0.6616$

$\mu/\rho = 0.1138$

$\mu = (0.1138)(11.35) = 1.292 \text{ cm}^{-1}$

$X_{\frac{1}{2}} = \frac{0.693}{1.292} = 0.537$ cm

(7) $2^n = \frac{R_o}{R} = \frac{42180}{10} = 4218$ $\therefore$ $n = 12.1$

(8) $X = nX_{\frac{1}{2}} = (12.1)(0.537) =$ $\underline{\underline{\text{6.5 cm of lead}}}$ - ANSWER

SHIELDING COOKBOOK

1. Calculate penetration of β particle.

   a. $E_{\beta^{\pm}max}$

   b. β range, page 123; ρ, page 65.

   c. $X = \frac{R}{\rho}$ (watch units)

2. Compute source strength for all electromagnetic radiation where $n \geq 0.03$.

   a. $S_{\gamma} = 0.56\ C\Sigma nE$

   b. $S_{brem} = 1.85 \times 10^{-4} CZ\Sigma nE^{2}_{\beta^{\pm}}$ (except $\beta^{\pm} \leq 0.1$ Mev)

   c. $S_{ann} = 0.572 C\Sigma n$

   d. $S_{total} = S_{\gamma} + S_{brem} + S_{ann}$

3. Compute dose rate at desired distance.

$$R_o = \frac{S_{total}}{d^2}$$

4. Compute $X_{\frac{1}{2}}$ for Electromagnetic Shielding.

   a. Pick greatest energy: $E_{\gamma max}$, $\frac{E_{\beta^{\pm}max}}{2}$, 0.511 Mev (for β^+).

   b. Calculate μ/ρ from tables on pages 137-139.

   c. $\mu = \mu/\rho \times \rho$ (ρ from page 65).

   d. $X_{\frac{1}{2}} = \frac{0.693}{\mu}$

5. Compute X.

a. $\frac{R_o}{R} = 2^n; \quad n = \frac{X}{X_{\frac{1}{2}}}$

b. Use 2^n Table or slide rule.

6. $X_{total} = X_{(Step\ 5)} + X_{(Step\ 1)}$ only for the same material.

RADIAC INSTRUMENT CALIBRATION TECHNIQUES

DF310

DF310, RADIAC INSTRUMENT CALIBRATION TECHNIQUES

I. Reference: TM 11-6665-204-12; TB 11-6665-204-12.

II. Lesson Objectives and Notes.

A. Procedures for calibration of the IM-174/PD and AN/PDR-27J radiac instruments with the TS-784A/PD radiac calibrator.

B. Safety precautions for handling, storage and use of radiac calibration devices.

C. Characteristics of other radiac calibration devices.

D. Procedures for calibration of the AN/PDR-60 radiac set with the AN/UDM-6 radiac calibrator.

III. Explanation.

A. TS-784( )/PD

1. Publications

a. TM 11-6665-204-12

b. DA Pam 310-4

2. Characteristics

a. Source

b. Activity

c. Radiation

d. Calibrates - IM-174( )/PD; AN/PDR-27( ); AN/PDR-60 (2R Scale); AN/PDR-39.

3. Controls

a. Label

b. License

c. Authorization for issue

d. RPO qualification

e. Radiation levels

4. Duties of RPO

5. Unpacking procedure

6. Safe use and handling

   a. Warning page basic TM

   b. Dosimetry

   c. Procedures

   d. Eye protection

   e. Special situations

7. Preliminary operations and procedures

   a. Calibration charts

   b. Decay curve

   c. Sample problem

      (1) What is the decay factor for a TS-784( ) calibrator that was calibrated 4 years ago?

      (2) 3 years ago?

      (3) If you are calibrating an IM-174A and the meter reading listed in the calibration chart for the 40K scale is 350 rad/hr, what is the corrected meter reading for the calibrator in (1) above?

B. AN/UDM-6.

1. Publications - TM 3-6665-203-10; TM 11-6665-208-15; TM 11-6665-221-15

2. Characteristics of the AN/UDM-6

   a. Source

   b. Activity

   c. Radiation

   d. Calibrates

3. Controls

   a. Labeling

   b. Licensee

   c. Authorization for issue

   d. RPO qualifications

4. Duties of custodian (RPO)

5. Unpacking procedure

6. Safe handling and use

7. Adherence test

IV. Practical Exercise

WARNING. Improper use of the TS784( )/PD, or failure to follow exactly the procedure outlined below and in TM 11-6665-204-12 could result in permanent injury or death.

A. ~~Safety.~~

1. All personnel must wear film badges and eye protection (safety goggles or prescription eye glasses) during the exercise.

2. No smoking, eating, drinking, or chewing in the calibration laboratory.

3. Always stand on the selector control side of the calibration assembly and never expose the face, hands, or body to the radiation port on the calibration assembly.

4. Always keep the radiation port aimed toward the wall and insure during assembly operations that it is not turned toward other personnel.

5. Always set the calibrator assembly selector control to 4mr/hr whenever the assembly is not being used.

6. Always cover the calibrator assembly with the safety shield when changing adapters and when the assembly is not being used. Also position the calibration assembly against the rearmost part of the workbench when not being used.

7. Always monitor-wash-monitor prior to leaving laboratory or work area.

B. Preparation of the TS-784A for Calibration.

1. Preparation for assembly.

a. Open cover and check the selector control and make certain that it is in the 4mr position.

b. Remove calibration assembly and place it face down on wooden block.

c. Remove following items from the carrying case:

(1) Calibration chart.

(2) IM 174( )/PD adapter.

(3) AN/PDR-27( ) adapter.

(4) AN/PDR-39( ) adapter (calibration case).

d. Set carrying case aside.

2. Mounting of calibration assembly.

a. Hook safety shield over front of calibration case.

b. Remove lead shield from calibration assembly (KEEP IT TURNED AWAY from eyes and body!).

c. Align radiation port of assembly with port of calibration case keeping rubber foot of assembly on table. Secure the assembly to the case with one of the short lead plate cover screws using the mounting hole closest to the left end of the adapter.

d. Lift up safety shield and place IM-174( )/PD adapter inside case so the radiation ports are aligned. Replace safety shield and secure adapter with the remaining two screws.

3. Wipe Test.

a. Take background count.

b. Break cotton swab to less than 5 inches, moisten, and hold wooden end with pair of tongs.

c. Remove safety shield and turn selector control to the 40K position. Insert the swab into the radiation port and thoroughly but gently swab the source.

NOTE: DANGER! Do not look directly into the calibration case or place your hand in front of the radiation port.

d. Turn the selector control back to the 4mr position and replace the safety shield.

e. Place swab on second shelf in pig and take a 2-minute count. (If a scaler is not available See Para 9-9, TM 11-6665-204-12 for alternate procedure.)

NOTE: If this count exceeds twice background call the safety officer.

f. Dispose of swab as radioactive waste.

C. Calibration of Radiacmeter IM-174/PD.

1. Preparation for calibration.

a. Loosen the four bolts in the bottom of IM-174 case and remove the case. (Fig A)

b. Remove the ion chamber from the IM-174/PD and place it in the IM-174/PD adapter with the beta window facing the calibration assembly. (Fig B)

c. Place the IM-174/PD case, meter face up, on the left side of the adapter.

d. Attach a ground wire from the pin on the IM-174/PD adapter to the pin on the resistor board.

e. Perform pre-operational check.

2. Performance check.

a. Check date on calibration chart. If the date is 1 year or more, apply the correction factor from the decay curve (para 2-5, TM 11-6665-204-12) to the reading listed in the calibration chart.

b. Turn the selector control to the 40K mr/hr position. If the meter is properly calibrated, it should read within ±10% of the value listed in the calibration chart.

c. Turn the selector control to 4K mr/hr and then to 400 mr/hr. The meter should read within ±10% of the value listed in the chart.

d. Return selector control to 4mr.

3. Calibration.

a. Turn selector control of the TS-784( )/PD to 40K mr/hr. The IM-174/PD should indicate the corrected value listed in the calibration chart within ±10%. If is does not, adjust the external calibration potentiometer until the correct reading is obtained.

b. Turn selector control to 4K mr/hr. If the reading is not within ±10%, adjust the external linearity potentiometer until the correct reading is obtained.

c. Return the selector control to 40K mr/hr and if necessary, again adjust the external calibration potentiometer.

NOTE: Check zero on meter after every step above.

d. Return the selector control to 4mr/hr and replace both cap-nuts being careful not to disturb the settings of the controls.

e. Turn the check switch on the IM-174 to ELEC CAL and if the meter does not read 500 rad/hr, adjust the internal calibration potentiometer (fig A) until it does.

f. Turn the check switch to LINEARITY and if the meter does not read 50 rad/hr, adjust the internal linearity potentiometer (fig A) until it does.

g. Remove ionization chamber, replace safety shield and reassemble the IM-174.

D. Calibration of Radiacmeter IM-174A/PD.

1. Preparation for calibration.

a. Loosen the four bolts in base of the case and remove instrument from the case.

b. Remove the ion chamber and place it in IM-174 adapter with the beta window facing the calibration assembly. Place the IM-174A, with meter facing up, to the left of the calibration case.

c. Press and hold the function switch to ZERO and adjust the SET control until the meter indicates zero.

d. Set the function switch to CHECK. The meter should indicate within the CHECK lines.

2. Performance check and calibration.

a. Turn selector control to 40K mr/hr, then to 4K mr/hr and then to 400 mr/hr. If the meter is properly calibrated, it should read within ±15% of the values listed in the calibration chart.

b. Turn the selector control to 40K mr/hr. If the meter does not indicate within ±15% of the correct value, adjust the calibration control until it does.

c. Check the readings with selector control in the 4K mr/hr and 400 mr/hr position. Adjust the calibration control until all settings read within ±15% of the proper value.

d. Press and hold the FUNCTION switch to the ZERO position. If the meter does not read zero, repeat step b.

e. Replace capnut and turn selector to 4 mr/hr.

f. Turn the SET control to OFF and remove the ion chamber from calibration case. Replace the safety shield an reassemble the IM 174A/PD.

E. Calibration of Radiac Set AN/PDR-27(*).

1. Preparation for calibration.

a. Remove the IM-174( )/PD adapter and place the AN/PDR-27 adapter in the calibrator case. Align the radiation ports with the large mounting clips to the rear. Replace the safety shield. Secure the adapter, using the long screw in the top screw hole.

b. Loosen the small compression nut at top of the small probe and then unscrew the large gland nut at top of the probe.

c. Loosen the bands holding the two probes together and slide the small probe forward, but not out of the bands.

d. Carefully remove the GM tube from small probe so as not to break the wires., If there is a plastic sheath around tube, remove it also.

e. Remove the GM tube from its mounting clips and place it in the small mounting clips of the AN/PDR-27( ) adapter.

f. Place the dummy tube from the AN/PDR-27( ) adapter into the clip assembly of the small probe in place of the GM tube.

g. Place the large probe in the large mounting clip of the adapter so that the beta window is closed and pointing toward the left side of the calibrator case (fig C).

h. Place the cables in the notch on the side of the adapter. Remove the safety shield and cover the adapter with plexiglass sheet.

2. Calibration.

a. Remove cap from the AN/PDR-27 calibration well.

b. Remove the attenuator from in front of the radiation port, turn the AN/PDR-27( ) range switch to 500 and the TS-784 selector control to the position indicated in the calibration chart. If the meter does not agree within ±15% of the correct value, adjust the 500-mr calibration control until it does. Return the selector control to 4-mr.

c. Insert the 50mr attenuator into the channel slides, turn the AN/PDR-27 range switch to 50 and the TS 784 selector control to the position indicated in chart. Adjust 50mr calibration control until correct indication is obtained. Return the selector control to 4mr.

d. Replace the 50mr attenuator with the 5mr attenuator. Turn the AN/PDR-27 range switch to 5 and the TS-784 selector control to the position indicated in the chart. Adjust the 5mr calibration control as necessary. Return the selector control to 4mr.

e. Remove large probe and disconnect dummy GM tube. Remove small GM tube from the mounting clips and reassemble the small probe.

f. Do NOT remove AN/PDR-27 adapter at this time.

g. Stand the calibration assembly on end and place the large probe 36 inches from the center of the calibration assembly.

h. Turn the range switch to 0.5 and adjust the 0.5 calibration control until the meter indicates within ±15% of the correct value.

i. Replace the calibration well cap.

F. Calibration of the 2r Range of Radiac Set AN/PDR-60.

Caution: Be sure the AN/PDR-60 is turned off. Allow 15 seconds for the high voltage power supply to discharge.

1. Remove the instrument from the case assembly by releasing the latch at each end.

2. Place the safety shield on the adapter.

3. Remove the GM tube and place it in the clips of the AN/PDR-60 adapter, orient the tube so the cap end is placed at the left of the nomenclature of the adapter, and the clip at the right of the nomenclature fits in the recessed area on the other metal contact of the tube. Place the adapter in the small clips of the AN/PDR-27 adapter so that the nomenclature is facing the radioactive source. Place the dummy tube connector of the AN/PDR-27 adapter in the AN/PDR-60 so that it duplicates the normal position of the GM tube. Remove safety shield and attenuator from radiation port and cover case with plexiglass sheet.

4. With the range switch in the 2r position, and the discriminator control in the AC-3 position, place the selector control in the position indicated in the calibration chart.

5. If the meter does not indicate within ±20% of the correct value, adjust the 2r calibration control until it does.

6. Return selector to 4mr and replace attenuator and safety shield. Turn off AN/PDR-60.

7. Remove the GM tube and other dummy GM tube and reassemble the AN/PDR-60.

8. Remove AN/PDR-27 adapter from calibration case. Replace safety shield.

G. Disassembly of TS-784A.

1. Make sure selector control is in 4mr/hr position.

2. Remove calibration assembly from case and attach lead shield. Replace it in lid of carrying case.

3. Replace items in the reverse order that they were removed.

4. Do not secure carrying case until it is inspected by the safety officer.

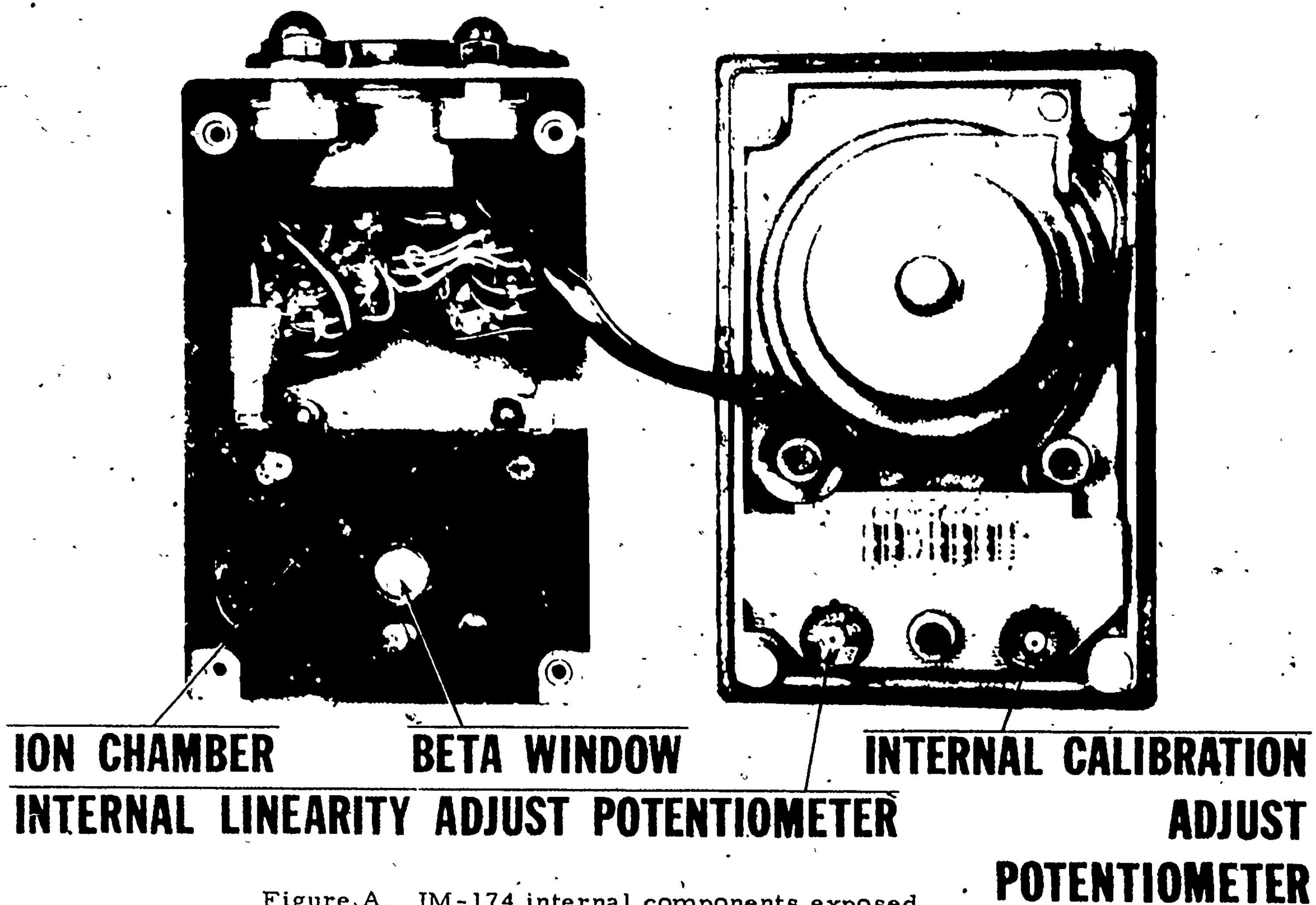


Figure A. IM-174 internal components exposed.

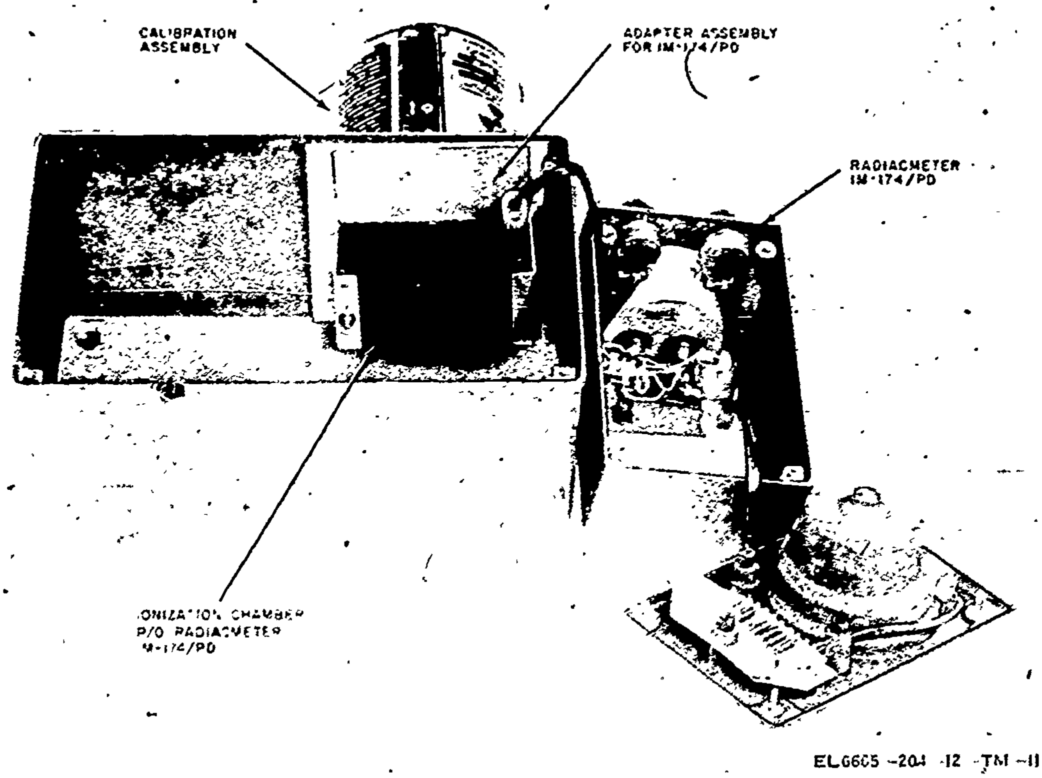


Figure B. Ionization chamber of radiacmeter IM-174/PD installed in IM-174(*)/PD adapter.

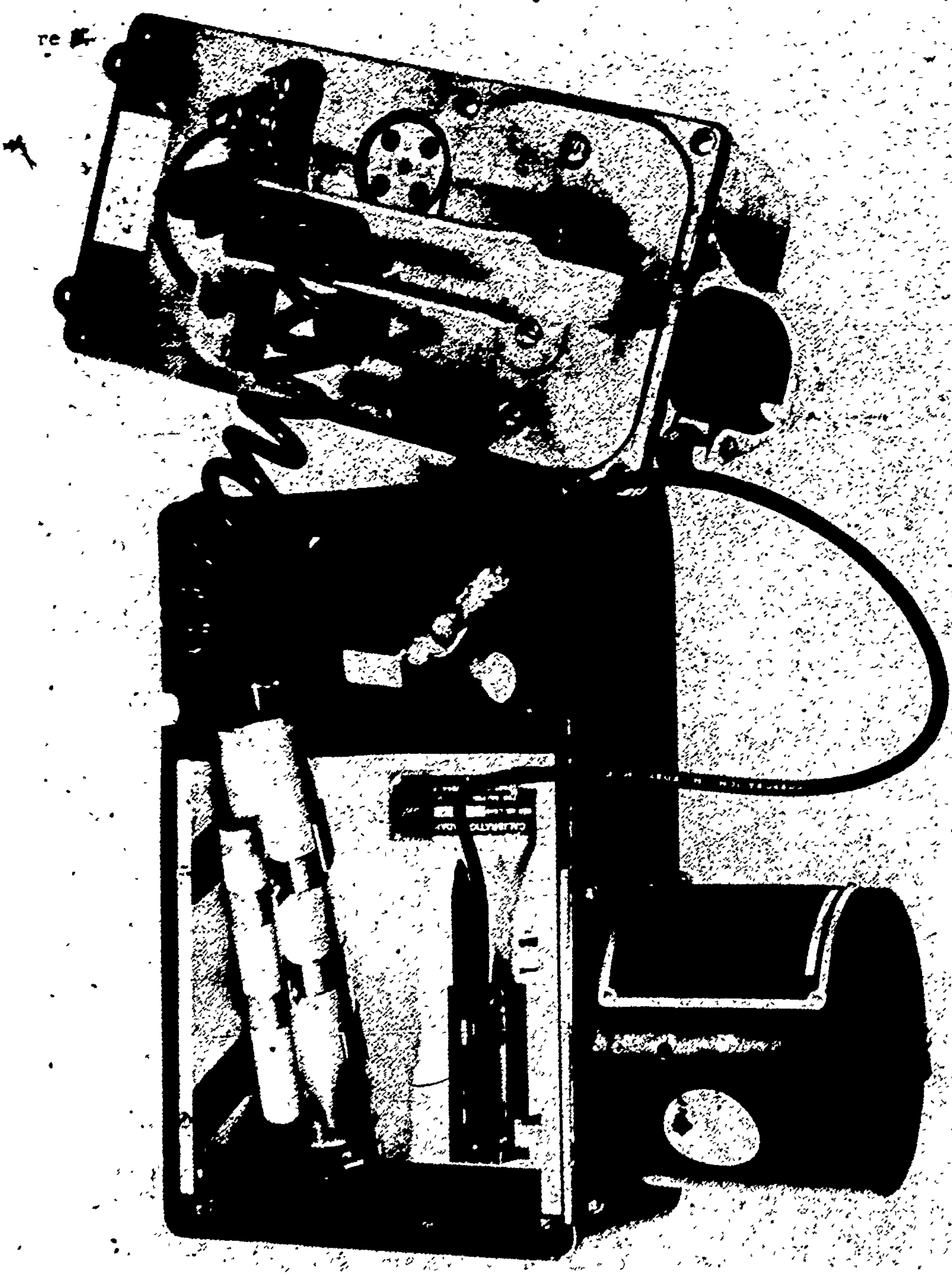


Figure C. Probes of the AN/PDR-27( ).

H. Safety.

1. All personnel will wear film badges during the exercise.

2. No eating, drinking, chewing or smoking in the calibration laboratory.

3. Monitor-wash-monitor prior to leaving the laboratory or work area.

4. Do not touch the radioactive sources attached to the lead jigs or attempt to remove the jigs from the case.

I. Wipe Testing AN/UDM-6 Calibrator.

1. Take 1-inch smear and mark one side with serial number of the set.

2. Moisten smear with water.

3. Smear the frame, jig, and mask of the calibrator.

NOTE: Do NOT smear the radioactive coated surface!

4. Allow smear to dry.

5. Monitor smear with AC-3 probe of AN/PDR-60 with range switch set at x1.0.

NOTE: Call instructor if radiacmeter indicates greater than 900 cpm above background!

J. Calibration of the AC-3 Probe of the AN/PDR-60 Radiac Set.

1. Preparation for calibration.

a. Remove the instrument from the case assembly by releasing the latch at each end.

Caution: Be sure the AN/PDR-60 is turned off. Allow 15 seconds for the high voltage power supply to discharge.

b. Using the shielded jumper cable connect the center conductor to the center post in case and connect the opposite end to the solder terminal above the high voltage block.

c. Connect the shield of the cable to the ground spring contacts in the case and on the chassis.

d. Turn the instrument range switch to 2r and set the probe selector switch to AC-3.

2. Calibration.

a. Remove the AC-3 discriminator capnut, and turn the range switch to X1.0.

b. Adjust the AC-3 discriminator until the meter reads 50 cpm or until the nut is turned full clockwise, whichever occurs first. Replace the capnut.

c. Remove the protective cover and check for light leaks.

d. Place the alpha probe on the lowest emission rate source and adjust the X1.0 calibration potentiometer until the average meter reading matches the cpm of the standard source.

e. Rotate the probe 180° and observe the reading. Adjust the X1.0 calibration pot until the average of the two readings equals the standard source cpm. The two readings should not deviate from the standard source cpm by more than 10%.

f. Repeat steps d and e for the X10, X100 and X1K scales using the corresponding alpha sources and calibration potentiometers.

g. Recheck the discriminator adjustment (para b, above). Reset discriminator, if necessary.

h. Recheck calibration on each range.

i. Turn instrument off. Allow 15 seconds for high voltage power supply to discharge. Remove shielded cable and replace instrument in case.

COMPUTATIONAL PROCEDURES IN PHYSICAL SCIENCES

DF320, COMPUTATIONAL PROCEDURES IN PHYSICAL SCIENCES

I. Reference: None

II. Lesson Plan Outline: None

III. Handouts: None

IV. Problems: Class and Home Study Problems.

1. What is the dose rate 5 meters away from a 500 Ci source of Cobalt-60? (Disregard bremsstrahlung)

2. What is the source strength due to the gamma radiation from 100 Ci of bromine-82? If lead were used for shielding, what source strength would be due to the beta radiation?

3. What thickness of lead is required to completely shield the particulate radiation and reduce the dose rate to 10 mrad/hr at 1 meter from a 1 Ci source of Arsenic-74?

4. A certain scaler has a resolving time of 5×10^{-5} minutes/count.

a. What is the maximum measurable observed counting rate?

b. This scaler registers an observed counting rate of 5000 cpm. What is the true counting rate?

5. Given the concentrations in air of

Ca	=	^{74}As	1.5×10^{-7} μCi/ml	soluble
Cb	=	^{82}Br	1.5×10^{-7} μCi/ml	soluble
Cc	=	^{89}Sr	1.2×10^{-8} μCi/ml	soluble

Does this area exceed the limitations for a restricted area?

6. During the monitoring of an area the following readings were obtained with the radiac instrument indicated. What are the respective levels of alpha contamination?

	Instrument	Type of Surface	Meter Reading
a.	IM-170	Wood floor	600,000 cpm
b.	IM-170	Cinder block wall	120,000 cpm
c.	IM-170	Marble workbench	2,000,000 cpm
d.	IM-170	Gravel roadway	680,000 cpm
e.	IM-170	Tile floor	1,600,000 cpm
f.	IM-170	Concrete walkway	700,000 cpm

7. A sample of 10 μCi activity gives an observed counting rate of 30,000 cpm in a scaler. The resolving time of the GM tube detector used is 30 μ sec/count.

a. What is the counting efficiency of the scaler?

b. What is the actual counting rate of the scaler?

8. It is required to completely shield the particulate radiation and reduce the dose rate to 10 mrad/hr at 1 meter from a 100 Ci source of beryllium-10. How much lead would be required for shielding?

9. a. What thickness of beryllium would be required to stop the beta particles from a 100 curie source of ^{91}Sr in equilibrium with its daughter product ^{91}Y? (Assume 100 Ci of ^{91}Sr and 100 Ci of ^{91}Y.)

b. What bremsstrahlung dose rate would result at 30 cm from the source?

c. What is the total unshielded dose rate 30 cm from the source?

d. What thickness of lead shield would be required in addition to a 2 cm iron shield to reduce the dose rate 30 cm from the source to 10 mrad/hr? (Assume that the shields are after the 0.723 cm of lead required to stop the beta particle.)

10. For determining source strength to include the effect of shielding, what energies and percentages should be considered for an equilibrium (1:1) mixture of bromine-80m and bromine-80?

11. You as Radiological Safety Officer have been asked to check a package for shipment of 1 Ci of $^{184}_{75}Re$, which has a source strength of 0.509 rhm. To ship this package, the reading at the surface of the package must not exceed 200 mrad/hr and at 1 meter from the surface must not exceed 10 mrad/hr. How much lead would be required to ship this package if the package is 1 meter to a side?

12. A 10 rhm source of barium-133 is kept in a storage room 4 feet away from the inner wall of the room. The walls are 12 inches thick of concrete. What is the maximum dose rate to which an individual outside the room may be exposed due to this source alone? (Neglect dose rate buildup.)

V. Solutions.

1. Data on ^{60}Co (page 389, Pam 25).

γ energy = 2.5057 Mev (99+%) total

$S = 0.56\ nCE$

$= 0.56 \times 1.0 \times 500\ Ci \times 2.505\ Mev$

$= 702\ rhm$

$\dot{R}_o = S/d^2$

$= 702\ rhm/(5m)^2$

$= \frac{702}{25}$

$= 28.1\ rad/hr$

2. Data on ^{82}Br (Scheme in problem)

β^- energy - 0.444 Mev (100%)

γ energy - 2.6483 Mev total

γ alone

$S = 0.56\ nCE$

$= 0.56 \times 1.0 \times 100\ Ci \times 2.6483\ Mev$

$= 148\ rhm$

β^- alone

$S = 1.85 \times 10^{-4}\ nCZE^2$

$= 1.85 \times 10^{-4} \times 1.0 \times 100\ Ci \times 82 \times (0.444\ Mev)^2$

$= 0.299\ rhm$

3. Data on ^{74}As -

β^- energies - 32%

1.35 Mev 18%

0.72 Mev 14%

β^+ energies - 29.5%

1.51 Mev 3.5%

0.91 Mev 26%

γ energies -

0.635 Mev 14%

0.596 Mev 61%

Maximum beta energy = 1.51 Mev.

$R = 680 \text{ mg/cm}^2$

$\rho_{Pb} = 11.35 \text{ gm/cm}^3 = 11350 \text{ mg/cm}^3$

$X = R/\rho$

$= 680 \text{ mg/cm}^2/11350 \text{ mg/cm}^3$

$= 0.0599$ cm - max β range = 0.06 cm

Find individual source strengths.

β^- and β^+ bremsstrahlung -

$S_{brem} = 1.85 \times 10^{-4}\ nCZE^2$

$S_1 = 1.85 \times 10^{-4} \times 0.18 \times 1 \text{ Ci} \times 82 \times (1.35)^2 = 0.00498$ rhm

$S_2 = 1.85 \times 10^{-4} \times 0.14 \times 1 \text{ Ci} \times 82 \times (0.69)^2 = 0.00101$ rhm

$S_3 = 1.85 \times 10^{-4} \times 0.035 \times 1 \text{ Ci} \times 82 \times (1.51)^2 = 0.00121$ rhm

$S_4 = 1.85 \times 10^{-4} \times 0.26 \times 1 \text{ Ci} \times 82 \times (0.91)^2 = \underline{0.00327 \text{ rhm}}$

$S_{brem} = 0.01047 =$

0.0105 rhm

β^+ annihilation

$S_{ann} = 0.572$ nC

$S_{ann} = 0.572 \times 0.295 \times 1$ Ci

$= 0.1687$ rhm $= 0.169$ rhm

γ energies -

$S_\gamma = 0.56$ nCE

$S_1 = 0.56 \times 0.14 \times 1$ Ci $\times 0.635$ Mev $= 0.0498$ rhm

$S_2 = 0.56 \times 0.61 \times 1$ Ci $\times 0.596$ Mev $= \underline{0.2036 \text{ rhm}}$

$S_{\gamma total} = 0.2534$ rhm $=$

0.253 rhm

$S_{total} = S_{brem} + S_{ann} + S_{\gamma total}$

$= 0.0105 + 0.169 + -/253$

$= 0.4325$ rhm $= 433$ mrhm

$R_o = S/d^2 = 433$ mrhm$/(1m)^2$

$= 433$ mrad/hr

$E_{\gamma max} = 0.635$ Mev $E_{ann} = 0.511$ Mev

$E_{\beta max}/2 = 1.51$ Mev$/2 = 0.755$ Mev

Use 0.755 Mev to calculate $X_{\frac{1}{2}}$.

$\mu/\rho = 0.0967$ cm^2/gm

$\rho = 11.35$ gm/cm^3

$\mu = (\mu/\rho)(\rho) = 0.0967$ cm^2/gm $\times 11.35$ gm/cm^3

$= 1.098$ cm^{-1}

$$X_{\frac{1}{2}} = 0.693/\mu = 0.693/1.098 \text{ cm}^{-1}$$

$$= 0.631 \text{ cm}$$

$$2^n = R_o/R = 433 \text{ mrad/hr}/10 \text{ mrad/hr}$$

$$= 43.3$$

$$n = 5.5 \ (2^n \text{ Table})$$

$$X = nX_{\frac{1}{2}} = 5.5 \times 0.631 \text{ cm}$$

$$= 3.47 \text{ cm}$$

$$X_{total} = 3.47 + 0.06$$

$$= 3.53 \text{ cm lead}$$

4. a. $R_o = 1/\tau$

$$= 1/5 \times 10^{-5} \text{ min/count}$$

$$= 20{,}000 \text{ cpm}$$

b. $R = \dfrac{R_o}{1 - R_o\tau}$

$$= \frac{5000 \text{ cpm}}{1 - 5000 \text{ cpm} \times 5 \times 10^{-5} \text{ min/count}}$$

$$= \frac{5000}{1 - 0.25}$$

$$= \frac{5000}{0.75}$$

$$= 6670 \text{ cpm}$$

5. $Ca/MPCa + Cb/MPCb + Cc/MPCc \leq 1$

$1.5 \times 10^{-7}/3 \times 10^{-7} + 1.5 \times 10^{-7}/1 \times 10^{-6} + 1.2 \times 10^{-8}/3 \times 10^{-8} =$

$0.5 + 0.15 + 0.4 = 1.05$

$1.05 > 1.$

Area is above restriction - no one can enter.

6. $\frac{\mu g\ ^{239}Pu}{m^2} = R(CF)$

	CF	x	R	=	$\frac{\mu g\ ^{239}Pu}{m^2}$
a.	$\frac{1}{240}$		600,000		2500
b.	$\frac{1}{200}$		120,000		600
c.	$\frac{1}{400}$		2,000,000		5000
*d.	$\frac{1}{170}$		680,000		4000
e.	$\frac{1}{400}$		1,600,000		4000
f.	$\frac{1}{200}$		700,000		3500

A gravel roadway is a very porous surface. Of the values given, this is the closest you can come. The value you obtain by use of $\frac{1}{170}$ is probably low for this type of surface and in an actual situation you may want to use an estimated CF of say $\frac{1}{100}$ or even $\frac{1}{75}$.

7. a. $10\ \mu Ci = 3.7\ (10)^5$ dps

$= 2.22\ (10)^7$ dpm

$$\text{Eff} = \frac{\text{observed counting rate}}{\text{actual disintegration rate}}$$

$$= \frac{30{,}000 \text{ cpm}}{2.22\ (10)^7 \text{ dpm}}$$

$= 1.35\ (10)^{-3}$ or 0.135%

b. Present actual counting rate -

$$R = \frac{R_o}{1 - R_o\tau} \quad (\tau = 30 \times 10^{-6} \frac{\text{sec}}{\text{count}} \times \frac{1 \text{ min}}{60 \text{ sec}} = 5 \times 10^{-7} \frac{\text{min}}{\text{count}})$$

$$= \frac{3(10)^4}{1 - 3(10)^4 \times 5\ (10)^{-7}}$$

$$= \frac{3(10)^4}{1 - 0.015}$$

$$= \frac{3(10)^4}{0.985}$$

$= 3.05 \times 10^4$ cpm

8. Data on ^{10}Be (from given scheme and data)

β^- energy = 0.555 Mev (100%)

No γ

Daughter (^{10}B) is stable.

Lead shield -

$R = 180\ mg/cm^2$

$\rho = 11.35\ gm/cm^3 = 11350\ mg/cm^3$

$X = R/\rho = 180\ mg/cm^2 / 11350\ mg/cm^3$

$= 0.0159$ cm

$S_{brem} = 1.85 \times 10^{-4}\ nCZE^2 = 1.85 \times 10^{-4} \times 100\ Ci \times 82 \times (0.555)^2 = 0.467\ rhm = 467\ mrhm$

$R_o = S/d^2 = 467\ mrhm/(1m)^2$

$= 467\ mrad/hr$

$E_{\beta max}/2 = 0.555\ Mev/2 = 0.278\ Mev$

$\mu/\rho = 0.533\ cm^2/gm$

$\mu = (\mu/\rho)(\rho) = 0.533\ cm^2/gm \times 11.35\ gm/cm^3$

$= 6.05\ cm^{-1}$

$X_{\frac{1}{2}} = 0.693/\mu = 0.693/6.05\ cm^{-1}$

$= 0.115\ cm$

$2^n = R_o/R = 467\ mrad/hr/10\ mrad/hr$

46.7

$n = 5.6$ (2^n Table)

$X = nX_{\frac{1}{2}} = 5.6 \times 0.115\ cm = 0.644\ cm$

$X_{total} = 0.644 + 0.0159 = 0.6599\ cm = 0.66\ cm$

9. a. Beta energies and %'s for ^{91}Sr:

2.67 Mev (27%)

2.03 Mev (4%)

1.36 Mev (29%)

1.09 Mev (33%)

0.62 Mev (7%)

Beta energies for ^{91}Y:

1.545 Mev (~ 100%)

Beta energy (max) = 2.67 Mev

$R = 1300\ \text{mgm/cm}^2$

$\rho = 1.8\ \text{gm/cm}^3 \times 1000\ \text{mgm/gm} = 1800\ \text{mgm/cm}^3$

$X = R/\rho = 1300/1800 = 0.723\ \text{cm}$

b. $S_b = 1.85 \times 10^{-4}\ nCZE^2$

$= (1.85 \times 10^{-4})(100\ \text{Ci})(4)\ nE^2$

$= 7.4 \times 10^{-2}\ nE^2$

$S_1 = (7.4 \times 10^{-2})(0.27)(2.67)^2 = 0.1424$ rhm

$S_2 = (7.4 \times 10^{-2})(0.04)(2.03)^2 = 0.0122$ rhm

$S_3 = (7.4 \times 10^{-2})(0.29)(1.36)^2 = 0.0397$ rhm

$S_4 = (7.4 \times 10^{-2})(0.33)(1.09)^2 = 0.0290$ rhm

$S_5 = (7.4 \times 10^{-2})(0.07)(0.62)^2 = 0.0020$ rhm

$S_6 = (7.4 \times 10^{-2})(1.0)(1.545)^2 = \underline{0.1769}$ rhm

$S_{total} = 0.4022$ rhm

$$R_{brem} = \frac{S}{d^2} = \frac{0.4022}{(0.3)^2} = 4.47\ \text{rad/hr}$$

c. Gamma energies and %'s for ^{91}Sr:

2.06 Mev (7%)

1.58 Mev (33%)

1.299 Mev (29%)

0.645 Mev (4%)

No significant γ energy for ^{91}Y.

$S = 0.56\ nCE$

$= (0.56)(100\ \text{Ci})\ nE$

$= 56\ nE$

$S_1 = (56)(0.07)(2.06) = 8.08$ rhm

$S_2 = (56)(0.33)(1.58) = 29.2$ rhm

$S_3 = (56)(0.29)(1.299) = 21.1$ rhm

$S_4 = (56)(0.04)(0.645) = \underline{1.45}$ rhm

$S_\gamma = 59.83$ rhm

$$R_\gamma = \frac{S}{d^2} = \frac{59.83}{(0.3)^2} = 665 \text{ rad/hr}$$

$R_{total} = R_\gamma + R_{brem} = 665 + 4.47 = 669.47$ rad/hr or 669 rad/hr

d. $E_{\beta max}/2 = \frac{2.67}{2} = 1.335$ Mev

$E_{\gamma max} = 2.06 = 0.645 = 1.415$ Mev

∴ use $E_{\gamma max}$ for μ/ρ value.

First find the effect of 2 cm of iron on the dose rate.

$\mu/\rho = 0.507 \text{ cm}^2/\text{gm}; \quad \rho = 7.86 \text{ gm/cm}^3$

$\mu = \mu \times \rho = (0.0507)(7.86) = 0.398 \text{ cm}^{-1}$

$$X_{\frac{1}{2}} \text{ (iron)} = \frac{0.693}{\mu} = \frac{0.693}{0.398} = 1.74 \text{ cm}$$

$n = X/X_{\frac{1}{2}} = 2 \text{ cm}/1.74 \text{ cm} = 1.15$

$2^n = 2.15$

$$R = \frac{R_o}{2^n} = \frac{669 \text{ rad/hr}}{2.15} = 311 \text{ rad/hr}$$

Now for lead -

$R_o = 311 \text{ rad/hr}; \quad R = 10 \text{ mrad/hr}$

$\mu/\rho = 0.0558 \text{ cm}^2/\text{gm}; \quad \rho = 11.35 \text{ gm/cm}^3$

$\mu = (0.0558)(11.35) = 0.633 \text{ cm}^{-1}$

$$X_{\frac{1}{2}} \text{ (lead)} = \frac{0.693}{\mu} = \frac{0.693}{0.633} = 1.09 \text{ cm}$$

$$2^n = \frac{R_o}{R} = \frac{311}{0.01} = 31100$$

$$n = 15.0$$

$$X = nX_{\frac{1}{2}} = (15.0)(1.09 \text{ cm}) = 16.4 \text{ cm}$$

10. Refer to decay scheme and data given.

For ^{80m}Br:

γ energy - 0.086 Mev (100%)
No particulate energy

For ^{80}Br:

β^- energy - 1.99 Mev (85%)
1.38 Mev (6%)
γ energy - 0.618 Mev (6%)

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11. <u>Find R at the Surface:</u>

$S = 0.509$ rhm

$d = 0.5$ m

$$R_o = \frac{S}{d^2} = \frac{0.509 \text{ rhm}}{(0.5 \text{ m})^2} = 2.036 \text{ rad/hr} = 2036 \text{ mrad/hr}$$

$R = 200$ mrad/hr

μ/ρ for 0.905 Mev gamma in lead $= 0.0797\ \text{cm}^2/\text{gm}$

$$\mu = \mu/\rho \times \rho = 0.0797 \times 11.35 = 0.905 \text{ cm}^{-1}$$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} \quad \frac{0.693}{0.905 \text{ cm}^{-1}} = 0.766 \text{ cm}$$

$$2^n = \frac{2036 \text{ mrad/hr}}{200 \text{ mrad/hr}} = 10.18$$

$n = 3.4$ (2^n Table)

$$X = nX_{\frac{1}{2}} = (3.4)(0.766 \text{ cm}) = 2.6 \text{ cm}$$

<u>Find R at One Meter from Surface:</u>

$d = 1.5$ m

$$R_o = \frac{S}{d^2} = \frac{0.509 \text{ rhm}}{(1.5 \text{ m})^2} = \frac{0.509}{2.25} = 0.226 \text{ rad/hr} = 226 \text{ mrad/hr}$$

$R = 10$ mrad/hr

$X_{\frac{1}{2}} = 0.766$ cm (Same as above)

$$2^n = \frac{226 \text{ mrad/hr}}{10 \text{ mrad/hr}} = 22.6$$

$n = 4.5$ (2^n Table)

$$X = nX_{\frac{1}{2}} = (4.5)(0.766 \text{ cm}) = \underline{\underline{3.45 \text{ cm}}}$$

To meet all requirements <u>3.45 cm</u> of lead must be used on a side.

12. Data on ^{133}Ba (Page 304, Pam 25)

Max γ energy = 0.382 Mev

Find μ/ρ (Page 139, Pam 25)

μ/ρ for 0.382 Mev = 0.0984 cm^2/gm

$\rho = 2.25\ gm/cm^3$ (Page 66, Pam 25)

$\mu = \mu/\rho \times \rho = (0.0984)(2.25) = 0.221\ cm^{-1}$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{0.221\ cm^{-1}} \doteq 3.14\ cm$$

$S = 10$ rhm

$d = (4\ ft + 1\ ft) \times 0.3048\ m/ft = 1.52\ m$

$$R_o = \frac{S}{d^2} = \frac{10\ rhm}{(1.52\ m)^2} = 4.33\ rad/hr = 4330\ mrad/hr$$

$$n = \frac{X}{X_{\frac{1}{2}}} = \frac{(12\ in)(2.54\ cm/in)}{3.14\ cm} = 9.71$$

$2^n = 830$ (2^n Table)

$$R = \frac{R_o}{2^n} = \frac{4330\ mrad/hr}{830} = \underline{\underline{5.23\ mrad/hr}}$$

DF340

LEAKAGE TEST

DF340, LEAKAGE TEST

I. Discussion.

A. Reference: None

B. Leak Testing.

1. General.

Currently the Atomic Energy Commission requires periodic testing of sealed sources. This requirement is further implemented by Department of the Army within its jurisdiction. In addition to these legal requirements for leak testing, the user has a moral obligation to these employees to protect them by periodic tests. The semi-annual test is a minimum requirement. Many agencies recommend leak testing each time a source is used.

2. Methods of Leak Testing.

Leak testing is divided into four general methods - immersion, cocoon, smear, and swipe. The latter two methods may be used as methods of surveying for removable surface contamination. In the conduct of all tests, personnel must be constantly aware of the techniques of safe handling and limit exposure by considering distance, shielding, time and quantity.

a. Immersion. The immersion method is one method for leak testing although generally impractical. It is the most difficult; time-consuming and requires a greater exposure of personnel than other techniques. Immersion consists of placing the source in a container of water which is held just below the boiling point for 30 minutes. The appearance of bubbles emanating from the source indicates that the source has a leak. The absence of bubbles does not indicate that the source is not leaking. After the source has been in the hot water for 30 minutes, it is removed and a sample of known volume of the water is taken, dried, and the residue is counted on an appropriate device. If contamination is present, it is presumed to have come from the source. The quantity of contamination removed from the source during the testing procedures is determined considering the efficiency of the counting system, the sample volume, and the total volume of water used in the test.

This test cannot be used on sources which are mounted in large assemblies, nor on sources having container material which will be adversely affected by the high temperatures and water.

One variation of the immersion test is the scrub test in which the samples are placed in a known volume of detergent solution, scrubbed with this solution, and a known volume of the solution is removed, dried and counted.

b. Cocoon. The cocoon test is applicable only to radium sources or other sources from which a gaseous radioactive material may leak. In this test the source is completely surrounded by a wad of cotton (or cocoon). This cocoon is placed inside an envelope or other container and kept for 24 hours. At the end of 24 hours the source is removed from the cocoon and the cocoon counted in an appropriate instrument. The quantity of contamination which leaked from the source is calculated considering the instrument efficiency.

A variation of the cocoon test is one which is used by the Public Health Service. They refer to this test as the jar lid test. It essentially allows for the decay of radon into heavy metal daughter products and the "plating out" of radon on a metal surface (the jar lid).

The way the jar lid test operates is to, first, get a small widemouth jar. The smaller the jar, in comparison to the lid surface, the better. The radium source is placed in the jar and the lid is placed on the jar. The jar is allowed to stand in this sealed position for a 24-hour period. A modification is to pack the jar lid with cotton or some other suitable absorbent material prior to sealing the jar. At the end of the 24-hour period, the jar is opened, and an immediate count is made on the jar lid with an alpha instrument. If cotton was used to pack the jar lid, then this cotton is treated in the same manner as the cocoon described before. If a reading is obtained on the instrument due to contamination on the jar lid, this constitutes evidence of a leaking source. This reading of the jar lid is only a qualitative determination of leakage.

c. Smear. The smear test is the most universally applicable technique of leak testing and is the best overall method of leak testing. It is also a method of testing an area for removable contamination. In this technique 100 square centimeters of the exterior of the source or the area are wiped. Some materials that may be used for the wiping procedure (known as wipes) are pieces of paper toweling, filter paper, cloth, gun patches, cotton, cotton swabs, tape (adhesive side to surface under test) or commercially prepared wipes. The wipe is generally about 2 inches (5 cm) across. They may be square or round. The wipes may be wet or dry depending on the circumstances. The test is performed by placing the wiping material on the surface, placing the fingertips on the wiping material and rubbing the material over the area being tested. Rubber or protective gloves should be worn if the contamination potential is high. If it is not desirable to come in close contact with the surface the wipe may be held in tongs or pliers. After smearing the 100 square centimeters the wipe is placed in an appropriate instrument and the removable contamination determined. If a wet wipe is used, it must be dried before counting.

d. Swipe. The swipe test is performed exactly like the smear test except an unspecified area is wiped. It is strictly a qualitative test. Some variations of the swipe test are:

(1) Line the inside of a container used to store a source with blotter or filter paper so that the source fits snugly. Prior to use remove the source, remove the paper, replace the source and count the paper on an appropriate instrument.

(2) Place a piece of adhesive material in contact with the surface of a source and allow it to remain for a period of time. Remove it and count the material in an appropriate counter.

II. Lesson Objectives and Notes.

A. Objectives.

1. In general terms, define sealed sources and leakage and give the purposes for leak testing.

2. In general terms, describe the following types of leakage test:

   a. Immersion

   b. Cocoon

   c. Smear

   d. Swipe or wipe.

3. Give the acceptable contamination levels for alpha, beta, and gamma emitters when removed by a leakage test.

4. Explain environmental test which can be performed.

5. Explain personnel monitoring test that can be performed.

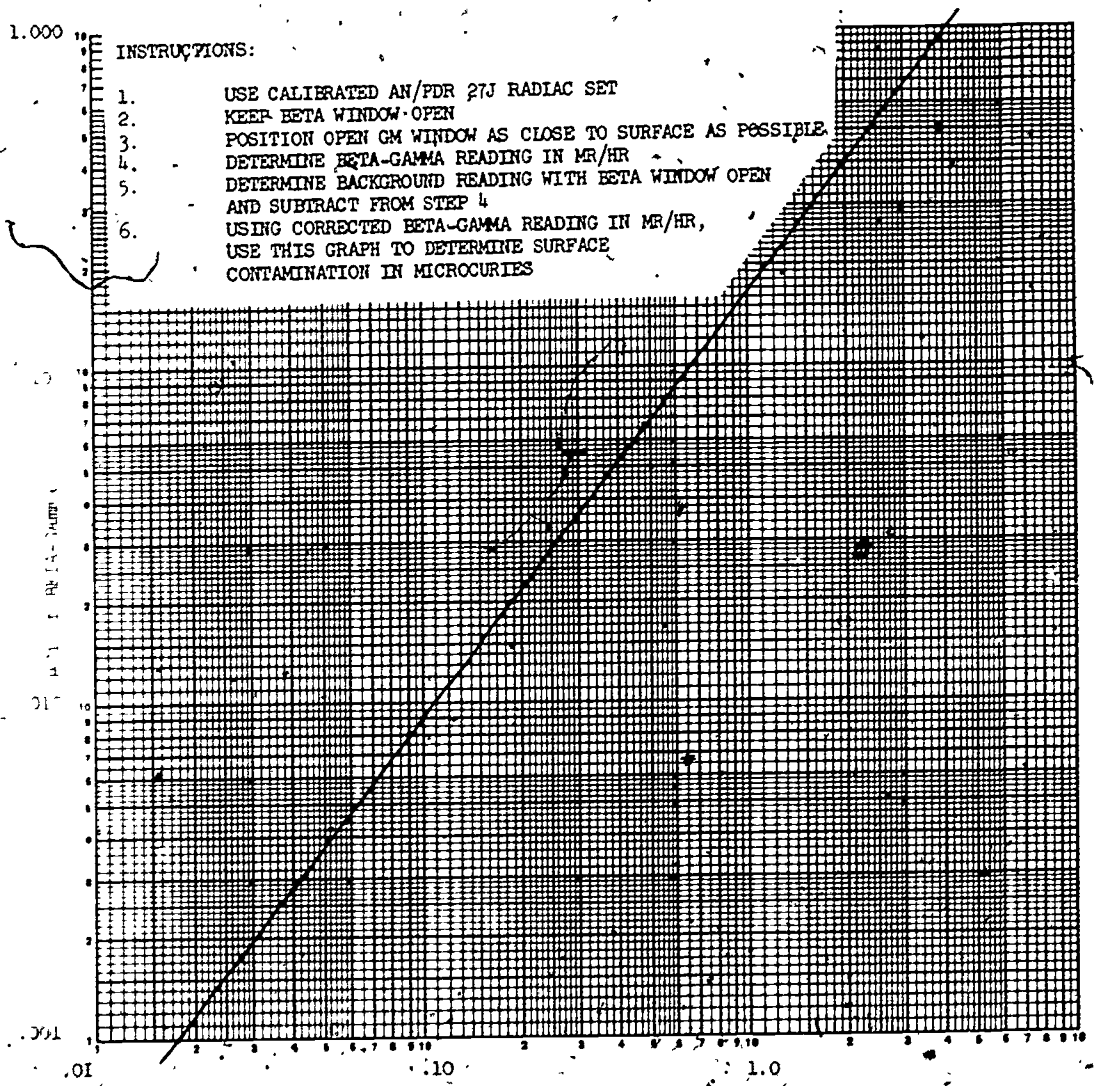
B. Notes:

III. Laboratory Exercise and/or Handout: None

IV. Problems: None

V. Solutions to Problems: None

MICROCURIES OF CONTAMINATION
VS
GM READING
(values are approximate)



ITEM	METER READING FIXED ACTIVITY		METER READING TRANSFERABLE ACTIVITY		SWIPE (c/m per 1 ft^2)		SMEARS (Dis/min per 150 cm^2)	
	Beta-Gamma	Alpha $c/m/cm^2$	Beta-Gamma	Alpha	Beta-Gamma	Alpha	Beta-Gamma	Alpha
Personal Clothing	.3 mrad/hr	10 cpm	N. D.	N. D.				
Skin and Under-Clothes	.1 mrad/hr	10 cpm	N. D.	N. D.				
Eating Area	.1 mrad/hr	10 cpm	N. D.	N. D.	100 cpm	50 cpm	200 dpm	10 dpm
"Cold" Areas	.1 mrad/hr	10 cpm	N. D.	N. D.	100 cpm	50 cpm	200 dpm	10 dpm
Respirators Inner	.1 mrad/hr	2 cpm	N. D.	N. D.				
Respirators Filter	.1 mrad/hr	20 cpm	N. D.	N. D.				
Anti-contamination Clothing-"Clean"	1.5 mrad/hr	100 cpm						
Anti-contamination Clothing being worn	5 mrad/hr max.	200 cpm	5 mrad/hr 5000 cpm limit	100 cpm				
Vehicles leaving controlled area.	.1 mrad/hr	20 cpm	N. D.	N. D.	100 cpm	50 cpm	200 dpm	10 dpm
Material and equipment leaving controlled area	.1 mrad/hr	20 cpm	N. D.	N. D.	100 cpm	50 cpm	200 dpm	10 dpm

N. D. = Not Detectable

CONTROL AND REPORTING OF RADIOACTIVE MATERIAL

DF350, CONTROL AND REPORTING OF RADIOACTIVE MATERIAL

1. General

a. Need for licensing

b. Method of licensing

c. Administrative control

d. Purpose of AR 725-1

e. Supplementation of AR 725-1

2. Definitions

a. Controlled item

b. Individually controlled item

Vu-Graph material used in DF 350. 1.

1. General.

a. To avoid the necessity of licensing each activity that possesses or uses licensable items, the USNRC has issued licenses and authorized the Department of the Army to control these sources. Lexington Blue Grass Army Depot has the license for the ^{90}Sr - ^{90}Y sources used in the TS-784()/PP Radiac Calibration. For its replacement, the AN/UDM-2 Radiac Calibrator, the license will be obtained through ECOM (AUTOVON 992-3493 or 3496) AMSEC-SF, Fort Monmouth, NJ. The National Inventory Control Point (NICP) for this item will also be at Fort Monmouth, ATTN: AMSEL-MM-S-CS-1A. The remainder of the NRC licenses are held at APG-EA for radioactive material for items used for issue. Control of these items is maintained at Armament Command, Rock Island Arsenal, ATTN: AMSAR-MMN-C, Rock Island, IL 61201. The Chief of CB Equipment Section handles all of these items (AUTOVON 793-4285 or 5757).

b. Listing of Vu-Graphs.

(1) Controlled item. This term applies to all items of supply listed in appendix A, AR 725-1, and appendix C, Major Command Supplemental Regulation 700-36. The items that are not listed as individually controlled items are controlled to the extent that all are nonexpendable, and that final disposition must be through the Army radioactive disposal facility.

(2) Individually controlled item. An item which must be controlled to the extent that its integrity and location are known by the licensee or his designated agents (control points) from its inception into the supply system until its disposal in an authorized waste disposal facility.

(3) NRC license. A document issued by the US Nuclear Regulatory Commission (NRC) pursuant to authority of the Atomic Energy Act of 1954 (68 STAT 919), 42 US Code 2011 et seq., which confers the right to procure, receive, store, transfer, use, export, and import specified radioactive items under stipulated conditions.

(4) Local RPO. An officer, enlisted person, or DA civilian employee appointed by the local installation or activity commander to supervise the radiation protection program for his command. As a minimum, his training and experience must meet the radiation protection requirements in the supply and technical bulletins and manuals pertinent to the types of sources used or stored at the installation or activity.

(5) Primary supply agency. US Army Armament Command, Rock Island Arsenal, Rock Island, IL, will be the primary supply agency for controlled items listed in AR 725-1.

(6) Radioactive material control point. An element which has been designated by a major commander to maintain administrative control of items within his command. Radioactive material control points will be established by all major CONUS commands and all oversea commands.

(7) Radioactive control officer. An officer, enlisted person, or DA civilian employee appointed by each major command to supervise the radiation protection program for the command. The qualifications of a radiological control officer should be superior to those of the local radiological protection officer for the sources listed in AR 725-1. He should have a scientific or engineering background and will have successfully completed one of the following:

(a) Radiological Safety Course given at APG-EA, or

(b). Basic Radiological Health Course given by US Public Health Service, or

(c) Eighty hours of formal training equivalent to (1) or (2) above covering the subjects listed below:

1. Principles and practices of radiation protection.

2. Radiological monitoring techniques.

3. Radiac instrumentation including operation, calibration, and limitations.

4. Mathematics sufficient to perform calculations necessary for the measurement of radioactivity and evaluation of actual or potential hazards to personnel.

5. Applicable Federal and Army regulations.

(8) NRC specific license.

(9) A specific license is required to produce, transfer, receive, own, possess, use, and import the quantities of byproduct material listed in 10 CFR 31, when used in accordance with pertinent regulations (10 CFR 20, App C).

(10) DA radioactive materials authorization. DA authorizations are required when radioactivity is 1 microcurie or greater and not subject to NRC specific license; also items irradiated during weapons test greater than 0.4 mrad/hr at any distance.

(11) DA written permits. Required for Federal and non-Federal agencies (e.g., civilian contractors) to store and use radiation sources on an Army installation.

(12) APG-EA and Lexington Blue Grass Army Depot.

(a) Preparation of license applications, renewals, and amendments.

(b) Publication of implementating procedures to conform with conditions required by the licenses.

(c) Publication of technical publications.

(d) Notification of higher commands and NRC in matters required by Federal and Army regulations.

(e) Maintain records on loss, damage, leakage, overexposure, inventory, inspections, and RMCO's.

(13) US Army Armament Command.

(a) Primary supply agency.

(b) Maintain records.

(c) Assign serial numbers.

(d) Coordinate all transfer responsibility.

(e) Coordinate all radioactive source procurement with APG-EA.

(14) Function of RMCP. Each principal installation commander will implement AR 725-1 and major command supplement regulation 700-63.

(a) Establish an RMCB for the installation area.

(b) Appoint on orders a qualified radioactive protection officer for the installation area.

(15) Installation RMCP.

(a) Exercise staff supervision over the radioisotope inventory and leak test reporting system.

(b) Provide coordination with and assistance to USAR and NG activities within the installation support area in preparing and submitting inventory and leak test reports.

(c) Review and approve the qualifications of all local radiological protection officers within the installation support area and send copies of those qualifications to the major command RMCP.

(d) Publish an implementing directive for this regulation and provide a copy to each user as well as information copy to the major command RMCP.

(e) Prepare update punchcards and submit to the major command RMCPG Radioisotope Inventory and Leak Test Report (RCS AMC-192) covering each calendar month. This report will be prepared in accordance with instructions at appendix A and dispatched to the command RMCP not later than the third working day following the close of the monthly reporting period. Reports indicating leaking sources or requests for disposition instructions will be submitted to this headquarters.

(f) Take actions indicated in paragraph 3-6b of AR 725-1 when qualified activity or unit radiological protection personnel are not available.

(g) Direct the actions indicated by paragraph 3-6 of AR 725-1 and report by telephone to CDR, APG-EA, any radiation overexposure alledged to have been received from any of the control items listed in table 3-1, AR 725-1, followed by notification of the major command RMCP. The RCS (AMC-191) MIN report will be submitted through the major command for approval of corrective action taken.

(h) Maintain records indicating the serial number and radioactivity at time of manufacture of the individual jigs within each UDM-6 Radiac Calibrator. This calibrator will be reported using <u>only the set serial number</u>.

(i) Maintain all records required by paragraph 3-8, AR 725-1 and paragraph 17, AR 700-52.

(j) Exercise approval authority for request for transfer of controlled items within the installation support area.

(k) Furnish the major headquarters one copy of all regulations and/or directives implementing this and related (e.g., AR 700-52 and 755-15) regulations, and one copy of the appointing order and summary of qualifications for the installation RPO.

(l) Route through the major command headquarters all correspondence pertaining to items reportable under AR 725-1 and Supplement 700-63.

(16) Action if no qualified RPO is available. If no qualified RPO is available at unit level, the installation RPO will take one of the following actions.

(a) Suspend requisition for the material, or

(b) Suspend use of material. In the interim, the CONUS Army RMCO is responsible for radiation safety and performance of leak tests, or.

(c) Transfer the radioactive items to a qualified installation.

(17) Unit or activity RPO.

(a) Will maintain informal records of the location, leak test results, and exposure reports for all radiation sources located within their respective units or activities.

(b) Will insure that all radioactive sources are used only by qualified persons and that the installation RPO is advised of any forthcoming changes of unit RPO.

(c) Will forward to the installation RMCP all inventory and leak test reports and requests for transfer or disposition of sources in accordance with installation implementing directives.

(d) May routinely return sources to Army depots for recalibration and leak testing (e.g., TS 784() calibrators) without requests for transfer or reports of change of unit or activity RPO provided that the transfer is made according to an SOP approved by the installation RPO concerned. Procedures must provide for shipment and handling in accordance with applicable directives for the transport and safe use of radioactive material.

(e) Will notify the installation RPO of radiation protection officer radiation overexposures attributed to the sources reported in accordance with AR 725-1 and Supplement 700-63 and promptly prepare an RCS (AMC-191) MIN report which will be submitted through radiological control channels to the CDR APG-EA. This report will be sent to the installation RPO within 24 hours of the overexposure discovery. Similar reports will be submitted for damaged sources.

(f) Notify installation RPO of abnormalities.

USE OF THIS REGULATION OUTSIDE OF US ARMY TRAINING AND DOCTRINE COMMAND IS FOR INSTRUCTIONAL PURPOSES ONLY.

DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY TRAINING AND DOCTRINE COMMAND
Fort Monroe, Virginia 23651

TRADOC Regulation
No 700-63

14 October 1974

Logistics
CONTROL OF RADIOACTIVE MATERIAL

Further limited supplementation is required. One copy of each supplement will be furnished HQ TRADOC, ATTN: ATLG-MAT.

1. Purpose.

a. This regulation establishes a radioactive material control point at HQ TRADOC, and prescribes procedure for the continuous inventory and leak test reporting of radiation sources (radioactive calibration and test items) listed in AR 725-1 and appendix C of this regulation.

b. It provides activities within CONUS that are under the command of the Commander, TRADOC, a means of reporting to meet requirements of AR 725-1 that will allow compilation and combined reporting to the primary supply agency.

*This regulation supersedes TRADOC Reg 700-63, 1 July 1973.

2. Background: There are several thousand items in the Army supply system that contain radioactive material. Most of these items, individually, represent only a minor health hazard and require very little special control. A few, listed in AR 725-1, contain Nuclear Regulatory Commission (NRC) controlled material procured on NRC licenses issued to AMC. The licenses require the sources to be used in accordance with Federal regulations, tested frequently for leakage, and used under the control of persons familiar with the radiation hazards incident to their use.

3. Scope.

a. Radiation source leak test and inventory reporting procedures described in this regulation apply to all radiation sources listed in table 3-1, AR 725-1 and appendix C of this regulation.

b. Nothing in this regulation will be interpreted to negate or supersede any NRC or AR 700-52 requirement pertaining to the control and safeguards of radioactive materials.

4. Objectives. The objectives of this inventory and reporting system are to--

a. Establish within TRADOC a single reporting system that will provide TRADOC installations and HQ TRADOC with current information on location, leak test results, and names of individuals responsible for the safe use, storage and disposal of the radioactive sources listed in AR 725-1 and appendix C of this regulation.

b. Provide for expeditious controlled transfer of radiation sources between TRADOC installations to insure that the sources are always used under the supervision of qualified Radiological Protection Officers (RPO).

c. Facilitate the expeditious modification or disposition of obsolete sources. (Only DA approved modifications will be performed on type classified sources (AR 700-52).)

d. Provide for the expeditious issue of disposition instructions for leaking or excess sources.

e. Provide control, on an installation basis, for the expeditious transfer of radiation sources between using activities and calibration and maintenance activities. (Transfer beyond the control of TRADOC must receive prior approval from the TRADOC Radiological Control Officer.)

f. Provide semiannual RCS (AMC-192) to the AMC NICP listing all reportable items in TRADOC. Provide installations with a semiannual

report RCS (AMC-192) in April and October for any corrective actions required. (appendix D.)

g. Provide special reports, as required, to locate or otherwise identify sources, e.g., a printout from TRADOC punch cards could identify all reportable sources at a given installation in support of NRC, TIG, USAEHA, or other radiation safety inspections.

5. Policy. For inventory and reporting purposes there will be one channel for reporting inventories and completing tests for radioactive leakage of calibration and test items of supply in use throughout TRADOC. The channel will be as follows:

From the principal TRADOC installation to the HQ TRADOC radioactive material control point to the respective AMC commodity command.

6. Responsibilities.

a. The Commander, TRADOC, will appoint on orders a qualified radiological control officer, who will--

(1) Exercise staff supervision over the TRADOC radioisotope inventory ~~and~~ leak test reporting system.

(2) Provide coordination with and assistance to other agencies, and activities within CONUS in preparing and submitting inventory and leak test reports.

(3) Maintain a file on current inventory and leak test reports.

(4) Prepare a consolidated report semiannually, as of 31 December and 30 June, listing the current data required by chapter 3 of AR 725-1 for each calibration and test item, and submit it to the AMC NICP and other agencies as specified in AR 725-1.

(5) Maintain a roster of the appointed installation RPO and approve their qualifications.

(6) Send a copy of his appointing orders and a summary of his qualifications to the Commander, APG-EA, in accordance with chapter 3 of AR 725-1.

b. Each principal TRADOC installation commander will implement this regulation, establish a radioactive material control point for the installation support area, and appoint on orders a qualified RPO for his installation support area who will--

(1) Exercise staff supervision over the radioisotope inventory and leak test reporting system.

(2) Provide coordination with, and assistance to USAR and NG activities within the installation support area in preparing and submitting inventory and leak test reports.

(3) Review and approve the qualifications of all local RPO within the installation support area and send copies of those qualifications to HQ TRADOC, ATTN: ATLG-MAT.

(4) Publish an implementing directive for this regulation and provide a copy to each user as well as information copy to HQ TRADOC.

(5) Prepare Punch Card Transmission Worksheet and submit to HQ TRADOC. This worksheet will be prepared in accordance with instructions at appendix A and dispatched to this headquarters, ATTN: ATLG-MAT, not later than the third working day following the close of the monthly reporting period. Reports indicating leaking sources or requests for disposition instructions for controlled sources may be submitted to this headquarters, at any time.

(6) Take actions indicated in paragraph 3-6b of AR 725-1 when qualified activity or unit radiological protection personnel are not available.

(7) Direct the actions indicated by paragraph 3-6f, AR 725-1 and report by telephone to the Commander, APG-EA, any radiation overexposure alleged to have been received from any of the control items listed in table 3-1, AR 725-1, followed by notification to HQ TRADOC. The RCS (AMC-191) MIN reports will be submitted through HQ TRADOC, ATTN: ATLG-MAT, for approval of corrective actions taken.

(8) Maintain records indicating the serial number and radioactivity, at time of manufacture, of the individual jigs within each UDM-6 Radiac Calibrator. This calibrator will be reported using only the set serial number.

(9) Maintain all records required by paragraph 3-8, AR 725-1 and paragraph 17 of AR 700-52.

(10) Exercise approval authority for request for transfer of controlled items within the installation support area.

(11) Furnish this headquarters one copy of all regulations and/or directives implementing this and related (e.g., AR 700-52 and 755-15) regulations, and one copy of the appointing order and summary of qualifications for the installation RPO.

(12) Route through this headquarters, ATTN: ATLG-MAT, all correspondence pertaining to items reportable under this regulation.

c. The TRADOC installation RPO and activity commanders will insure that calibration and test items of supply are used under the supervision of qualified persons who know the hazards involved and the safety precautions needed when they are being used. Unit commanders will appoint unit RPO in accordance with AR 40-14, AR 700-52, and AR 725-1. Commanders of TRADOC installations on which there are tenanted or satellited activities not under their command will provide radiological protection area support needed to meet the requirements of AR 725-1 and this regulation, as agreed to by the commanders of the separate elements. Unit RPO will be appointed for separate elements only when the scope and diversity of the local program warrant. Unit commanders will publish implementing regulations and procedures to reflect agreements between TRADOC installations and tenanted or satellited activities.

d. Unit or activity RPO--

(1) Will maintain informal records of the location, leak test results and exposure reports for all radiation sources located within their respective units or activities.

(2) Will insure that all radioactive sources are used only by qualified persons and that the installation RPO is advised of any forthcoming changes of unit RPO.

(3) Will forward to the installation radiological control point all inventory and leak test reports and requests for transfer or disposition of sources in accordance with installation implementing directives. The worksheet at appendix B will be used for reporting any changes.

(4) May routinely return sources to Army depots for recalibration and leak testing (e.g., TS-784( ) Calibrators) without requests for transfer or reports of change of unit or activity RPO, provided that the transfer is made according to an SOP approved by the installation RPO concerned. Procedures must provide for shipment and handling in accordance with applicable directives for the transport and safe use of radioactive materiel.

(5) Will notify the installation RPO of radiation overexposures attributable to the sources reported in accordance with this regulation and promptly prepare a RCS (AMC-191) MIN report which will be submitted through radiological control channels to the Commander, APG-EA. This report will be sent to the installation RPO within 24 hours of the overexposure discovery. Similar reports will be submitted for damaged sources.

7. References.

a. AR 40-14, Control and Recording Procedures Occupational Exposure to Ionizing Radiation.

b. AR 40-27, Personnel Radiation Exposures.

c. AR 55-55, Transportation of Radioactive and Fissile Materials Other than Weapons.

d. AR 385-30, Safety Color Code Markings and Signs.

e. AR 385-40, Accident Reporting Records.

f. AR 700-52, Licensing and Control of Sources of Ionizing Radiation.

g. AR 700-64, Radioactive Commodities in the DOD Supply System.

h. AR 725-1, Special Authorization and Procedures for Issues, Sales and Loans. (Chapter 3 is titled: Control of Radioactive Calibration and Test Items of Supply.)

i. AR 750-27, Army Metrology and Calibration System.

j. AR 755-15, Disposal of Unwanted Radioactive Material.

k. SB 700-20, Army Adopted Items of Materiel.

l. TB 43-180, Calibration Requirements for the Maintenance of Army Materiel.

APPENDIX A

INSTRUCTIONS FOR PREPARING TRADOC FORM 465-R (PUNCH CARD TRANSMISSION WORKSHEET). NOTE: SLASH ALL NUMERIC ZEROS: "Ø".

CC 1-6. Enter the Unit Identification Code (UIC) of the unit or activity that possesses this item. Show only six numbers or letters, beginning with a "W" in the first position of all Army units. (No alphabetic "O's" or "I's" may be used in the UIC.)

CC 7-19. Enter the NSN thirteen digits. Do not enter ~~dashes~~. Use the NSN for the radioactive source rather than the NSN for kits or sets that contain a radiation source with a separate NSN. (See appendix C.)

CC 20-24. Show the set serial numbers with five positions. If the inventory lists a serial number of an item with less than five positions precede the number with zeros.

CC 25-28. Express the determined source activity as follows:

	XØØ7 (7 microcuries)
	10Ø- (100 millicuries)
	ØØ1K (1 curie)
	14C5 ($1.4X10^6$ counts per min)
	28D5 ($2.8X10^6$ disintegrations per min)
TS-1230A	4ØC5 ($4X10^6$ counts per min)
M3A1	126- (126 millicuries)
TS-784( )	Ø4Ø- (40 millicuries)
UDM-6	14C5 ($1.4X10^6$ counts per min)
M8	5ØC2 (5,000 counts per min)

NOTE: The activity of these sources may vary considerably and should be reported as indicated on the source. (Either the activity at date of manufacture or as determined by recalibration may be reported.)

CC 29-32. Use four digits to show the year and month that the source activity reported in columns 25 through 28 was determined. The first two digits will show the year; and the last two digits, the month; e.g., February 1958, "58Ø2", December 1966, "6612". If this date cannot be determined, show "UNK" in the first three spaces, leaving column 32 blank.

CC 33-35. Use three digits to show the year and month that the item was received at the installation; e.g., December 1965, "512". If the date cannot be ascertained, show "UNK".

CC 36-43. If transferred, enter the shipment number/Government Bill of Lading (GBL) as one letter and seven numbers. The GBL must appear on all reports deleting or adding an item from the inventory.

CC 44-45. Leave blank.

CC 46-50. A unit reporting an item as being received will enter either the UIC or ARLOC (DA Cir 525-10-3) from where the source was shipped. A unit deleting an item will enter the UIC of the receiving unit, if transferred, or the ARLOC (DA Cir 525-10-3) of the location to which an item was shipped for disposal. (See CC 73-77.)

CC 51-52. Leave blank.

CC 53-56. Enter the Julian date on which the item was shipped for transfer or disposal.

CC 57-58. Leave blank.

CC 59.

a. Enter the number "1" for all reports for NSN 6665-00-973-1123.

b. Enter the number "2" for all reports for NSN 6665-00-856-8235.

c. Enter the number "3" on all reports for NSN 6665-00-692-6601 and 6665-00-752-7790.

d. Enter the number "4" for all reports for NSN 6665-00-767-7497.

e. Enter the number "5" for all reports for NSN 6665-00-618-1348.

f. Leave blank for reports on all other NSN.

CC 60-62. Enter the date of the last leak test, using three digits as shown for columns 33 through 35. "NON" will be shown for the M8 Uranium Test Sample, NSN 6665-00-618-1348.

CC 63-65. Use three digits to show the results of the leak test performed on the date shown in columns 60-62 (showing microcurie X 10^{-5}; e.g., 0.002 microcuries, would be shown as "200"). If an activity exceeds .005 microcuries, refer to paragraph 3-14b, AR 725-1. Round off wipe test results to the nearest 10^{-5} microcuries, e.g.,

0.001700 microcuries - is shown as:	170
0.000030 microcuries - is shown as:	003
0.000005 microcuries - is shown as:	001
Less than 0.000005 microcuries - is shown as:	--1

CC 66-68. Code the method of leak test analysis as follows:

"N" (in CC 66) to indicate that the wipe test was checked locally and found to be free of detectable contamination, followed by the appropriate abbreviation (in CC 67 and 68) of the activity to which the wipe was sent for a more accurate analysis. (See below for proper abbreviations.)

"D" (in CC 66) to indicate that an analysis was reported, followed by the abbreviation (in CC 67 and 68) of the activity performing the wipe test analysis. (See below for proper abbreviations.)

SD - Sacramento Army Depot
LX - Lexington Army Depot

"NXX" to indicate that the analysis was performed with locally available measuring equipment of the required sensitivity. (AN/PDR-27 is not adequately sensitive.)

"LEK" to indicate that the source was found to be leaking.

Example: A wipe test checked locally with AN/PDR-27 was found to be free of detectable contamination. The wipe test was mailed to the Lexington Army Depot for a more accurate analysis. The results were not received within 30 days; therefore, the report was submitted with "UNK" in columns 63 through 65 and "NLX" in columns 66 through 68. Upon receiving this report the RPO requested that the wipe test report be retransmitted. When received, the wipe test results of .003 microcuries were then reported as "300" in columns 63 through 65 and "DLX" in columns 66 through 68.

CC 69. Use an alpha character to indicate the type of report as follows:

"I" - for an initial or recurring semiannual inventory.
"W" - for a change in date of the last wipe test.
"K" - for correction of erroneous information previously reported. This letter code must be used in conjunction with both Transaction Codes (CC 80) (i.e., "delete previously reported data" and "add new corrected data"). Two cards are required to complete the correction.

"E" - to indicate that the item is excess to the needs of the unit or activity having custody. Sources will be reported excess only as separate items, not as physical components of other sets.

"L" - for a change to the unit or activity having custody. (A corresponding change will be made to columns 1 through 6, Unit Identification Code.) CC 46-50 and CC 53-56 must be filled in.

"D" - for completion of disposal actions and item is to be deleted from the inventory. CC 36-43, 46-50, and 53-56 must be filled in.

CC 70-72. Show the date of the report by digits, indicating the year with the first digit and the month with the last two digits, e.g., February 1968: "802".

CC 73-77. Enter the Army Location Code identifier from DA Cir 525-10-3 that best depicts the actual source location.

CC 78-79. Enter the installation USACSC reporting code from Appendix E.

CC 80. Enter the appropriate transaction code, as follows:

"A" - for add.

"D" - for delete. (NOTE: If "delete" card has a "K" in CC 69, there will also be an "add" card, if an "L" or "D" is in CC 69, CC 36-43, and 46-50 must be completed.)

"C" - for change. Used with "W" in CC 69.

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET

RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)

(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W																					

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

TRADOC FORM Sep 74 465-R Previous editions are obsolete. Indicate numeric zero as Ø. Print one character in each space. 10½x8

APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

APPENDIX E

US ARMY COMPUTER SYSTEMS COMMAND INSTALLATION REPORTING CODES (TRADOC EXTRACT)

NOTE: Radioactive sources located on subinstallation or within the installation support area will use only the principal installation reporting codes as given.

	INSTALLATIONS	CSC* CODE
1.	Fort Belvoir	12
2.	Fort Benning	13
3.	Fort Bliss	14
4.	Fort Dix including Carlisle Barracks	29
5.	Fort Eustis including Fort Monroe and Fort Story	32
6.	Fort Gordon	33
7.	Fort Benjamin Harrison	36
8.	Fort Jackson	48
9.	Fort Knox including Columbus Spt Facility	50
10.	Fort Leavenworth	52
11.	Fort Lee including Cp Hill and Cp Pickett	53
12.	Fort McClellan	57
13.	Fort Ord including Hunter-Leggett, Pres of Monterey, and Cp Roberts	69
14.	Fort Polk	72
15.	Fort Rucker	77
16.	Fort Sill	82
17.	Fort Leonard Wood	90

*CC 78-79 in Punch Card Transmission Worksheet

APPENDIX D

SAMPLE INSTALLATION REPORT

PREPARED 3C JUL 74

RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS AMC-192) PCN: AGB-014

BY INSTALLATION, PRIORITY AND SER NBR

INST CODE	UIC	N S N	SER NR	SORC ACT	DATE ACT	DATE REC	SHPMT NO	SHIPPED FROM/TO	DATE SHIP	PRT CODE	DATE TEST	TEST RSLT	ANAL METH	TYP RPT	DATE RPT	STA CODE	T/C
73	WAH3AA	6665007527730	A4131	025-	7206	207				3	311	002	DLX	W	311	20736	A
73	WJVA29	6665007527795	A4184	025-	7303	310				3	311	001	DLX	W	311	20736	A
73	WAH3AF	6665007527790	DG361	075-	7305	207				3	311	005	DLX	W	311	20736	A
73	WAH3AA	6665006976601	00C46	030-	7303	205				3	311	005	DLX	W	311	20736	A
73	WOVA29	6665007677497	A1122	14C5	7303	312				4	311	001	DLX	W	311	20736	A
73	WAG9AA	6665007677497	A1167	14C5	7303	206				4	311	001	DLX	W	311	20736	A
73	WOVA21	6665006181348	33179	32C2	7206	201				5	NON			W	310	20736	A
73	WOVA21	6665006181348	00180	34C2	7206	201				5	NON			W	310	20736	A
73	WOVA27	6665006181348	00280	32C2	7303	209		WE3JA	3229	5	NON			L	310	20736	A
73	WOVA29	6665006181348	00281	50C2	7208	205				5	NON			W	310	20736	A

13

TRADOC Reg 700-13

The proponent of this regulation is the Office of the Deputy Chief of Staff for Logistics. Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications) through channels to the Cdr, TRADOC, ATTN: ATLG-MAT, Fort Monroe, VA 23651.

FOR THE COMMANDER:

OFFICIAL:

B. E. HUFFMAN, JR.
Major General, GS
Chief of Staff

V. W. Bolton
V. W. BOLTON
Colonel, AGC
Adjutant General

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Edgewood Arsenal, ATTN: SAREA-TS/SAREA-SF
ECOM, ATTN: AMSEL-SF

1. References and Application.

a. References:

(1) AR 72[illegible]-1.

(2) TRADOC Supplement Reg 700-63.

(3) AR 700-52.

(4) TRADOC Supplement No 1 700-52.

(5) AR 700-64.

(6) TM 3-260.

(7) TM 3-261.

b. Application - Problem.

(1) Prepare a Radioisotope Inventory and Leak Test Report (RCS-AMC-192) using the worksheet format outlines in Appendix A, TRADOC regulation 700-63, Pertinent Data.

(a) Aberdeen Proving Ground, Maryland station identifier - 01567. The CSC Code for Aberdeen Proving Ground is 02.

(b) Consolidated Supply, APG-UIC-WOU 293.

(c) US Army Ordnance Center and School - WID4AAA.

(d) Radioactive Source Set M3A1, NSN 6665-00-856-8235, serial number 60809, source activity 126 millicuries, material 60, manufactured 5 October 1971.

(e) Source received on the installation on 1 Nov 1974 with a GBL number of 5B784622.

(f) The radioactive source set was transferred from Consolidated Supply to the Radiation Protection Officer, USAOC&S on 5 Nov 1974, and a wipe test was performed on receipt and checked locally with a AN/PDR-27(J) and found to be free from detectable contamination. The wipe test was mailed to Lexington Blue Grass Army Depot for detailed analysis.

(2) Prepare the follow-up report which is transmitted to the RMCP on receipt of wipe test results of 2 X 10^{-6} microcuries on 27 November 1974.

(3) Prepare the report which would be made out on the same item, on 5 May 1975. At that time, assume that the wipe test showed 6 X 10^{-3} microcuries of contamination. USAOC&S Health Physics Office performed the analysis.

(4) You have received disposition instructions from APG-EA. Complete the report covering the following disposal actions. On 6 June 1975, the item was consolidated with other radioactive waste materials and transferred to the Radioactive Material Disposal Facility, per bill of lading number Z1234567 (APG-EA Station Identifier - 00429).

(5) Attached is an incorrect report (marked problem 5). All the information entered on the worksheet is correct; however, one bit of information is missing. Complete the action(s) required to correct this omission. Date of preparation is 8 April 1975.

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET
RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)
(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W																					

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

TRADOC FORM Sep 74 465-R Previous editions are obsolete.

Indicate numeric zero as Ø. Print one character in each space.

APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET

RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)

(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W																					

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
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Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

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10½x 8

APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET

RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)

(TRADOC Reg 700-63)

UIC						NSN													Set-Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W																					

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
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Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

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APPENDIX

REPORTABLE RADIATION SOURCES

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6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator ~~TS784A~~
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET

RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)

(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W																					

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

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APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
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APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET

RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)

(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W																					

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number								
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

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APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
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6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

PROBLEM 1.

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET
RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)
(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W	D	4	A	A	A	6	6	6	5	Ø	Ø	8	5	6	8	2	3	5	6	Ø	8

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Ø	9	1	2	6	–	7	1	1	Ø	4	1	1	5	B	7	8	4	6	2	2		

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
W	U	2	9	3			4	3	Ø	9			2	4	1	1

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 526-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
U	N	K	N	L	X	I	4	1	1	Ø	1	5	6	7	Ø	2	A

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APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

PROBLEM 2

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET
RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)
(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W	D	4	A	A	A	6	6	6	5	Ø	Ø	8	5	6	8	2	3	5	6	Ø	8

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Ø	9	1	2	6	-	7	1	1.	Ø	4	1	1	5	B	7	8	4	6	2	2		

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
W	U	2	9	3			4	3	Ø	9			2	4	1	1

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
-	-	1	D	L	X	W	4	1	1	Ø	1	5	6	7	Ø	2	C

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APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

PROBLEM 3

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET
RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)
(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W	D	4	A	A	A	6	6	6	5	Ø	Ø	8	5	6	8	2	3	5	6	Ø	8

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Ø	9	1	2	6	–	7	1	1	Ø	4	1	1										

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
													2	5	Ø	5

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
6	Ø	Ø	L	E	K	W	5	Ø	5	Ø	1	5	6	7	Ø	2	C

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APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

PROBLEM 4

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET
RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)
(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W	D	4	A	A	A	6	6	6	5	Ø	Ø	8	5	6	8	2	3	5	6	Ø	8

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Ø	9	1	2	6	-	7	1	1	Ø	4	1	1	Z	1	2	3	4	5	6	7		

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
Ø	Ø	4	2	9			5	1	5	7			2	5	Ø	5

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
6	Ø	Ø	L	E	K	D	5	Ø	6	Ø	1	5	6	7	Ø	2	D

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APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

PROBLEM 5

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET

RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)

(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W	D	8	A	B	C	6	6	6	5	Ø	Ø	7	5	2	7	7	9	Ø	4	4	2

Number		Real Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
4	8	Ø	4	Ø	–	7	Ø	Ø	9	2	Ø	8										

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
													3	4	Ø	3

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Ø	Ø	3	D	L	X	K	4	Ø	4	Ø	1	5	6	7	Ø	2	D

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APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
6665-00-973-1123	Radiac Calibration TS1230A
6665-00-856-8235	Radioactive Source Set M3A1
6665-00-692-6601	Radiac Calibrator TS784
6665-00-752-7790	Radiac Calibrator TS784A
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6665-00-618-1348	Radioactive Test Sample M8

PROBLEM 5 SOLUTION

APPENDIX B

PUNCH CARD TRANSMISSION WORKSHEET
RADIOISOTOPE INVENTORY AND LEAK TEST REPORT (RCS-AMC-192)
(TRADOC Reg 700-63)

UIC						NSN													Set Serial		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
W	D	8	A	B	C	6	6	6	5	Ø	Ø	7	5	2	7	7	9	Ø	4	4	2

Number		Rad Source Activity				Date Activity Determined				Date Received			Shipment Number									
23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
4	8	Ø	4	Ø	–	7	Ø	Ø	9	2	Ø	8										

Shipped To/Received From							Date Shipped						Priority Code	Date Test		
46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62
													3	4	Ø	5

Test Result			Analysis Method			Type Rept	Date This Report			Army Location Code (ARLOC) DA Cir 525-1-3)					CSC Inst Code		Trans Code
63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Ø	Ø	3	D	L	X	K	4	Ø	4	Ø	1	5	6	7	Ø	2	A

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APPENDIX C

REPORTABLE RADIATION SOURCES

NSN	ITEM
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6665-00-752-7790	Radiac Calibrator TS784A
6665-00-767-7497	Radiac Calibrator AN/UDM-6
6665-00-618-1348	Radioactive Test Sample M8

LICENSING AND SOP WRITING

DF370, LICENSING AND SOP WRITING

I. References and Discussion.

Radiological Safety Handbook GE439.

Title 10, CFR; AR 700-52; USAEC "how to get a License to use Radioisotopes;" USACMLCS Memo 385-2.

II. Student Performance Objectives.

A. Using texts and references, make application for an NRC license, completing and complying with all requirements.

B. Using texts and references, make application to the NRC for renewal and amendment of an NRC license, complying with all requirements.

C. Using texts and references, comply with DA guidance on routing and staffing of request for NRC licenses.

D. Using texts and references, make application through DA for permission to use and hold non-NRC licensed material.

E. Using texts and references, comply with DA directives on the control and reporting of radioactive material.

F. Using texts and references, prepare and administrate standard operating procedures for a radiological safety program.

III. Handouts.

Vu-Graphs used in DF370.

A. 10 CFR Part 20, "Standards for Protection Against Radiation"

1. Standards for safety application to all persons possessing or using licensed radioactive material.

2. Basic radiation safety regulations.

B. 10 CFR Part 30, "Rules of General Applicability to Licensing of Byproduct Material"

1. Basic rules for licensing of radioisotopes.

2. Certain aspects of byproduct material licensing covered in Parts 31 through 36.

C. 10 CFR Parts 31 and 32.

1. 10 CFR Part 31, "General Licenses for Certain Quantities of Byproduct Material and Byproduct Material Contained in Certain Items"

2. 10 CFR Part 32, "Specific Licenses to Manufacture, Distribute, or Import Exempted and General Licensed Items Containing Byproduct Material"

D. Other Considerations.

1. 10 CFR Part 33, "Specific Licenses of Broad Scope for Byproduct Material"

2. 10 CFR Part 34, "Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations"

3. 10 CFR Part 35, "Human Use of Byproduct Material"

4. 10 CFR Part 36, "Export and Import of Byproduct Material"

5. 10 CFR Part 71, "Packaging of Radioactive Material for Transport"

E. Information Submitted.

1. Criteria - radiation protection

2. Criteria - approval of license application

3. Rules - transfer of licensed material

4. Record - keeping requirements

5. Rules - amendment, modification, suspense, or revocation of licenses

F. Guides.

1. Federal Radiation Council

2. National Council on Radiation Protection

3. National Council on Radiation Protection and Measurements

4. International Commission on Radiation Protection

G. Preparing an Application.

1. Submitted on NRC Form 313a

2. NRC Form 313a - has sheet of instruction to closely follow

3. Supplemental sheet - may be attached

4. Two copies - NRC Form 313a and supplemental sheets

5. Obtain forms - Director, Division of Material Licensing, USNRC, Washington, D. C. 20545

H. Safety Evaluation.

1. Training and experience

2. Instrumentation

3. Equipment

4. Facilities

5. Procedures proposed for use for protection

6. Waste disposal

I. Training.

1. Principle and practices of radiation safety

2. Radioactivity measurements

3. Standardization

4. Monitoring techniques and instruments

5. Mathematics and calculations basic to use and measurement

6. Biological effects

7. Handling and use commensurate with the types and quantities to be employed

J. Other Information.

1. Name and address

2. Quantity, type, and chemical or physical form of radioisotopes to be used

3. Purpose for which used

K. License Authorization.

1. Receive

2. Acquire

3. Owned and imported

4. Transfer to other NRC or state licenses

L. Responsibility.

1. Material, equipment and procedures used

2. Personnel who use material and equipment

   a. Sufficiently trained

   b. Follow management instruction

   c. Follow safety rules

   d. Period checks

M. Records.

1. Receipt

2. Transfer

3. Disposal

4. Radiation exposure of persons in program

5. Surveys made to evaluate radiation safety

N. Purpose.

1. Provides - procedures for submission of application

2. Prescribes - control of radioactive material not licensed by NRC

3. Provides - guidance for DA agencies for use of radioactive material

   a. procuring

   b. coordinating

   c. controlling

   d. other sources of ionizing radiation.

O. Request for Non-licensed Material.

1. Description of facility

2. Type and activity

3. Name and qualification of individual responsible

4. Purpose for which used

5. Detection instruments to be employed

6. Health protection measures

7. Monitoring provisions

P. Control.

1. Procurement
2. Receipt
3. Storage
4. Inventory
5. Surveillance

Q. Safety Procedures.

1. Purpose
2. Philosophy
3. Safety rules
4. Instruction to personnel
5. Radiation protection standards
6. Surveys
7. Caution signs, labels, and signals
8. Radiological emergencies

IV. Problems: None

V. Solutions: None

FORM [illegible]

U.S. NUCLEAR REGULATORY COMMISSION

Page 1 of 4 Pages

BYPRODUCT MATERIAL LICENSE No. 1-2861-1 AMENDMENT NO. 12
(L67)

THIS COPY IS FOR YOUR FILES

Pursuant to the Atomic Energy Act of 1954 and Title 10, Code of Federal Regulations, Chapter 1, P[illegible], Licensing of Byproduct Material, and in reliance on statements and representations heretofore made by the licensee, a license is hereby issued authorizing the licensee to receive, acquire, own, possess, transfer and import byproduct material listed below, and to use such byproduct material for the purpose(s) and at the place(s) designated below. This license shall be deemed to contain the conditions specified in Section 183 of the Atomic Energy Act of 1954, and is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

Licensee	
1. Name: Department of the Army U.S. Army Ordnance Center and School 2. Address: Radiological Branch Technical Division Aberdeen Proving Ground, Md 21005	In accordance with application dated September 27, 1965, 3. License number 1-2861-1 is amended in its entirety to read as follows: 4. Expiration date December 31, 1967 5. Reference No.

6. Byproduct material (element and mass number)	7. Chemical and/or physical form	8. Maximum amount of radioactivity which licensee may possess at any one time
A. Any byproduct material with Atomic Nos. 3-83 inclusive (See page 2)	A. Any (See page 2)	A. 100 millicuries of each (See page 2)

9. Authorized use

A. Research and Development as defined in Section 30.4(k), Title 10, Part 34, Code of Federal Regulations, Chapter 1, "Rules of General Applicability to Licensing of Byproduct Material." Laboratory and field instruction in radiological defense. (See page 2)

CONDITIONS

10. Unless otherwise specified, the authorized place of use is the licensee's address stated in Item 2 above.

11. The licensee shall comply with the provisions of Title 10, Part 20, Code of Federal Regulations, Chapter 1, "Standards for Protection Against Radiation."

12. Byproduct material shall be used by, or under the supervision of, individuals designated by the U. S. Army Ordnance Center and School Isotopes Committee.

13. In lieu of the control device requirements of Section 20.203(c)(2), the Pelham Range radiological field shall be enclosed by a fence six-feet high (four feet of hog wire topped by at least three strands of barbed wire). All gates into the Pelham Range radiological field shall be padlocked at all times except for entry by authorized personnel.

14. A. Each sealed source acquired from another person and containing byproduct material, other than Hydrogen 3, with a half-life greater than thirty days and in any form

(See page 2)

MATERIAL LICENSE

Supplementary Sheet

Continued From Page 1

License Number 1-2861-1
(L67)

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AMENDMENT NO. 12

6. Byproduct material (element and mass number)	7. Chemical and/or physical form	8. Maximum amount of radioactivity which licensee may possess at any one time
B. Cesium 137	B. Oak Ridge National Laboratory Sealed Source	B. 1 source of 135 curies
~~C. Cobalt 60~~	~~C. Oak Ridge National Laboratory Sealed Sources~~	~~C. 750 curies contained in 50 sources of 15 curies each~~
D. Cobalt 60	D. Gamma Industries Encapsulated Sealed Sources	D. 15,180 curies contained in 1020 sources of 15 curies each
E. Cobalt 60	E. Oak Ridge National Laboratory Sealed Source	E. 1 source of 8 curies

Authorized use continued:

B. For use in Model AN/UDM-1A Radiac Calibrator for calibration of instruments.
C. and D. For use in Pelham Range radiological field for training in radiological defense.
E. For use in Model AN/UDM-1 Radiac Calibrator for calibration of instruments.

Condition 14.A. continued:

other than gas shall be tested for contamination and/or leakage prior to use. In the absence of a certificate from a transferor indicating that a test has been made within six months prior to the transfer, the sealed source shall not be put into use until tested.

B. Each sealed source fabricated by the licensee shall be tested for contamination and/or leakage immediately after fabrication. If the test reveals the presence of 0.005 microcurie or more of removable contamination, the licensee shall repair and/or decontaminate and retest the source. Sealed sources fabricated for distribution and containing byproduct material (with the exception of byproduct material with a half-life not exceeding thirty days, byproduct material in the form of gas, and Iridium 192) shall, in addition to an initial test upon fabrication, be stored for a period of seven days and retested prior to transfer to another person or as otherwise specifically provided for in this license.

C. Each sealed source containing byproduct material, other than Hydrogen 3, with a half-life greater than thirty days and in any form other than gas shall be tested for leakage and/or contamination at intervals not to exceed six months except that each source designed for the purpose of emitting alpha particles shall be tested at intervals not to exceed three months.

(See page 3)

License Number 1-2861-1
(L67)

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AMENDMENT NO. 12

Condition 14. continued:

D. The test shall be capable of detecting the presence of 0.005 microcurie of radioactive material on the test sample. The test sample shall be taken from the sealed source or from the surfaces of the device in which the sealed source is permanently or semipermanently mounted or stored on which one might expect contamination to accumulate. Records of leak test results shall be kept in units of microcuries and maintained for inspection by the Commission.

E. If the test required by Subsection A. or C. of this condition reveals the presence of 0.005 microcurie or more of removable contamination, the licensee shall immediately withdraw the sealed source from use and shall cause it to be decontaminated and repaired or to be disposed of in accordance with Commission regulations. A report shall be filed within 5 days of the test with the Director, Division of Materials Licensing, U.S. Nuclear Regulatory Commission, Washington, D.C. 20545, describing the equipment involved, the test results, and the corrective action taken. A copy of such report shall also be sent to the Director, Region II, Division of Compliance, USAEC, 50 Seventh Street, Northeast, Atlanta, Georgia 30323.

15. In lieu of the requirements of Condition 14.A., sealed sources in the Pelham Range radiological field shall be each tested according to the following schedule:

A. Ten percent of the sources shall be tested for leakage and contamination at six-month intervals.

B. If any leaking sources are found in the ten percent tested, the leaking sources shall be withdrawn from use and repaired or disposed of and another ten percent of the sources shall be tested.

C. If any leaking sources are found in the second ten percent tested, the leaking sources shall be withdrawn from use and repaired or disposed of and all the sources in the Pelham Range radiological field shall be tested.

D. If any leaking sources are found in the remaining sources tested, they shall be withdrawn from use and repaired or disposed of.

16. In lieu of the requirements of Section 20.203(f)(4), 10 CFR 20, sealed sources in the Pelham Range radiological field may be labeled as follows:

Radiation Symbol (in appropriate color)
DANGER RADIOACTIVE MATERIAL DO NOT HANDLE
(Serial Number)
Notify Military Authorities if Found
U.S. Army Ordnance Center and School
Aberdeen Proving Ground, Md 21005

(See page 4)

U.S. NUCLEAR REGULATORY COMMISSION
BYPRODUCT MATERIAL LICENSE
Supplementary Sheet

License Number 1-2861-1 (L67)

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AMENDMENT NO. 12

Condition 16. continued:

The licensee shall maintain a permanent record of the quantity of activity in each source and the date of measurement.

17. Except as specifically provided otherwise by this license, the licensee shall possess and use byproduct material described in Items 6, 7, and 8 of this license in accordance with statements, representations, and procedures contained in application dated September 27, 1965, and amendment thereto dated December 8, 1965.

For the U.S. Nuclear Regulatory Commission

Date DEC 2 0 1965

by Nathan Bassin
Isotopes Branch
Division of Materials Licensing
Washington, D. C. 20545

BYPRODUCT MATERIAL LICENSE

Supplementary Sheet

License Number 01-02861-01

Amendment No. 15

This Copy is For Your Files

Department of the Army
U.S. Army Ordnance Center and
School
Radiological Branch
Technical Division
Aberdeen Proving Ground, Md 21005

In accordance with application dated November 29, 1967, License Number 01-02861-01 is amended as follows:

Items 6., 7., 8., and 9. are amended to add:

6. Byproduct material (element and mass number)	7. Chemical and/or physical form	8. Maximum amount of radioactivity which licensee may possess at any one time
F. Cesium 137	F. Minnesota Mining and Manufacturing Company Model 4F6S Sealed Sources	F. 2000 millicuries total-no single source to exceed 500 millicuries

9. Authorized use

F. Research and Development as defined in Section 30.4(q), Title 10, Part 30, Code of Federal Regulations, Chapter 1, "Rules of General Applicability to Licensing of Byproduct Material." Laboratory and field instruction in radiological safety and radiological defense.

Item 9.A. is amended to read:

9.A. Research and Development as defined in Section 30.4(q), Title 10, Part 30, Code of Federal Regulations, Chapter 1, "Rules of General Applicability to Licensing of Byproduct Material." Laboratory and field instruction in radiological safety and radiological defense.

For the U.S. Nuclear Regulatory Commission

Date FEB 7 1968

by [signature] Isotopes Branch

Division of Materials Licensing
Washington, D. C. 20545

DEPARTMENT OF THE ARMY
OFFICE OF THE DEPUTY CHIEF OF STAFF FOR LOGISTICS
WASHINGTON, D.C. 20310

LOG/PE-ISB

SUBJECT: Byproduct Material License No. 01-02861-01

THRU: ~~Commanding General~~
~~United States Continental Army Command~~ 19 FEB 1968
~~ATTN: ATCPS-TNG-MBC~~
~~Fort Monroe, Virginia 23351~~

~~Commanding General~~
~~Third United States Army~~
~~ATTN: AJAGL-D-S~~
~~Fort McPherson, Georgia 30330~~

~~Commanding Officer~~
~~U. S. Army School/Training Center~~
~~Fort McClellan, Alabama 36201~~

TO: Commanding Officer
U.S. Army Ordnance Center
and School
Aberdeen Proving Ground, Md 21001

Forwarded herewith is Amendment No. 15 to NRC Byproduct Material License No. 01-02861-01 for U. S. Army Ordnance Center and School, Aberdeen Proving Ground, Md.

FOR THE DEPUTY CHIEF OF STAFF FOR LOGISTICS:

1 Incl
Amendment No. 15

C. M. McKEEN, JR.
Colonel, GS
Chief, PEMA Execution Division

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Section II

STATE REGULATION

If you are located in any of the States which exercise regulatory authority by agreement with the Commission, you must apply to the particular State regulatory agency instead of the NRC for a license to possess and use radioisotopes. Such States are called "Agreement States." State licensing and regulation of nuclear materials under agreement with the NRC was authorized by Congress in 1959. Twenty-one States (Alabama, Arizona, Arkansas, California, Colorado, Florida, Idaho, Kansas, Kentucky, Louisiana, Mississippi, Nebraska, New Hampshire, New York, North Carolina, North Dakota, Oregon, South Carolina, Tennessee, Texas, and Washington) had concluded agreements with the Commission by mid-1969, and 24 others had enacted legislation authorizing such agreements. (Names and addresses of Agreement State regulatory agencies are listed in Appendix A.)

The NRC's Division of State and Licensee Relations cooperates closely with the Agreement States in the development and execution of their regulatory programs. A continuing objective of this coordination is to maintain compatibility of the State programs with the NRC program.

The Agreement States already are responsible for issuing over 40 percent of all current licenses for the use of radioisotopes. The States also have jurisdiction over the use of other sources of radiation—radium, X-rays and accelerator-produced radioisotopes—which are not covered by the Nuclear Regulatory Commission. Agreement State authorities carry out an on-site inspection program to determine whether licensees are complying with the State's regulations and the requirements of their licenses.

Licenses issued by Agreement States are recognized by the Commission as general licenses to conduct the same activity in non-agreement States, subject to pertinent provisions in NRC regulations, provided certain conditions are met. The Agreement State licensee must: (1) register with the NRC prior to engaging in activity in the non-agreement State by filing NRC Form 241, "Report of Proposed Activities in Non-Agreement States"; (2) dispose of, or transfer radioactive material only to persons specifically licensed to receive it or who are exempted from licensing; (3) possess or use materials in non-agreement States as authorized by the Agreement State license no more than 20 days in any 12 consecutive months. Agreement States recognize NRC licenses under similar reciprocity procedures.

Section III

SAFETY STANDARDS AND REGULATIONS

In applying for a license to use radioisotopes, you will need to understand the radiation safety standards and certain other regulations issued by the NRC. These rules are designed to protect workers and the general public from harmful exposure to radiation. They have been adopted by the Commission as the basis for its licensing and safety controls, in accordance with the provisions of the Nuclear Regulatory Commission for protecting health and safety. The regulations are published under Title 10 of the Code of Federal Regulations.[2]

The following regulations relate to radioisotope licensing and safety:

10 CFR Part 20, "Standards for Protection Against Radiation," which contains standards of safety applicable to all persons possessing or using licensed radioactive materials. This is the basic radiation safety regulation.

10 CFR Part 30, "Rules of General Applicability to Licensing of Byproduct Material," which contains the basic rules for licensing of radioisotopes, but certain aspects of byproduct material licensing are dealt with in Parts 31 through 36. These different aspects are indicated by the titles:

10 CFR Part 31, "General Licenses for Certain Quantities of Byproduct Material and Byproduct Material Contained in Certain Items."

10 CFR Part 32, "Specific Licenses to Manufacture, Distribute, or Import Exempted and Generally Licensed Items Containing Byproduct Material."

10 CFR Part 33, "Specific Licenses of Broad Scope for Byproduct Material."

10 CFR Part 34, "Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations."

10 CFR Part 35, "Human Uses of Byproduct Material."

10 CFR Part 36, "Export and Import of Byproduct Material."

10 CFR Part 71, "Packaging of Radioactive Material for Transport."

These regulations prescribe, among other things, the kind of information which must be submitted to the NRC by applicants for licenses in the respective categories; the criteria for radiation protection; the criteria for approval of license applications; rules pertaining to the transfer of licensed materials; record-keeping requirements, and rules relating to the amendment, modification, suspension or revocation of licenses.

In developing NRC regulations on radiation safety, the Commission is guided by the recommendations of the Federal Radiation Council, the National Council on Radiation Protection and Measurements, and the International Commission on Radiological Protection. Industry representatives and other interested persons are invited to submit comments on proposed rules.

The NRC Division of Radiation Protection Standards continually reviews radiation safety requirements and makes necessary revisions to keep safety regulations abreast of developments in the use of atomic energy and man's growing knowledge about the effects of radiation.

[2] For the convenience of licensees desiring such a service, the NRC provides prompt distribution of all rule changes through the Government Printing Office on a subscription basis. The service consists of a complete loose-leaf set of NRC Rules and Regulations (Title 10, Chapter 1, Code of Federal Regulations) and replacement pages reflecting amendments to effective rules and proposed rules as they are published in the Federal Register, keeping the set up to date. In addition to the rules and regulations, the set includes a cross-referenced section of statements of consideration published at the time each regulation was issued or amended. NRC Rules and Regulations, including all replacement pages for an indefinite period, may be ordered only from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. The price is $7.00 ($2.00 additional for foreign mailing).

366-104 O—69——2

Section IV

YOU MAY NOT HAVE TO GET A SPECIFIC LICENSE

Many prospective users of radioisotopes will not have to obtain specific licenses because of *exemptions* applying to particular kinds, quantities and uses, or because of *general licenses* which permit possession and use of specified radioisotopes within stated limitations. Both the general licenses and the exemptions are published in the regulations. Pertinent parts of the regulations are reproduced in Appendix C (for general licenses) and Appendix D (for exemptions).

A. General Licenses

General licenses are effective without the necessity for applications or the issuance of licensing documents to particular persons. A general license permits the possession and use of specified kinds and quantities of radioisotopes, subject in some cases to certain regulatory requirements. In some instances, registration with NRC is required to use radioisotopes under a general license.

Most materials and products available under a general license and the limitations upon quantities and uses are listed in Part 31, "General Licenses for Certain Quantities of Byproduct Material and Byproduct Material Contained in Certain Items." (See Appendix C.) Radioisotopes which may be used under general licenses are for the most part incorporated in products, devices or equipment manufactured under specific licenses issued by the Commission, or by an Agreement State. If you want to use a commercially distributed device containing radioisotopes in an industrial operation, your supplier should be able to tell you whether it is distributed under a general license and, if so, the conditions under which it is to be used. For example, certain equipment purchased under a general license must be installed by the manufacturer or distributor, and after installation the device may not be transferred, abandoned, or disposed of except by transfer to persons specifically licensed to receive it.

There are other general licenses besides those included in Part 31. A general license for medical use of limited quantities of designated radioisotopes is contained in Part 35, "Human Uses of Byproduct Material," which lists the routine diagnostic procedures authorized under this general license. General licenses for the export of specified kinds and quantities of radioisotopes are published in Part 36, "Export and Import of Byproduct Material." Importation of certain quantities of radioisotopes is permitted under a general license contained in Part 31. (All of these are contained in Appendix C.)

Users or prospective users of radioisotopes should acquire an understanding of the regulatory provisions relating to their use of byproduct material because the use of radioactive material is subject to some requirements unless the use is under an exemption from licensing.

B. Exemptions

The exemptions from licensing requirements are set forth in detail in Part 30, "Rules of General Applicability to Licensing of Byproduct Material. (See Appendix D.) Of particular interest may be the exemptions for small quantities of certain radioisotopes when incorporated in specified products. The manufacture and distribution of such products are generally subject to specific licensing requirements. An example of a product containing radioactive material which is exempted is a watch whose hands and dials are made luminous by application of the radioisotope tritium or promethium-147. The *manufacturer* of luminous watch dials, however, must be specifically licensed.

Exemptions from licensing requirements are based mainly on a determination by the Commission that the exempted classes or quantities of byproduct material or kinds of uses or users will not constitute an unreasonable risk to the common defense and security or to public health and safety. Any interested person may apply to the Commission for exemption of a particular class, quantity, or use of radioisotopes, under these criteria, or the Commission may make an exemption on its own initiative.

Section V

QUALIFYING FOR A SPECIFIC LICENSE

If you desire to possess and use radioisotopes in a manner, form or quantity not exempted from licensing and not covered by a general license, you will have to apply for and obtain a specific license from the Commission (or an Agreement State) issued for specified uses. (The applicant may be an individual, firm, corporation, association, public or private institution or agency.)

A. Preparing an Application

Here is how you go about applying for a license to use radioisotopes:

> Your application ordinarily should be submitted on Form NRC–313, the basic application form for byproduct material licenses. (There are other application forms for special purposes.) Form NRC–313 is accompanied by a sheet of instructions which you should follow closely in preparing your application. (A completed sample Form NRC–313 is reproduced in Appendix E, with the instruction sheet.) Supplemental sheets may be attached to Form NRC–313. Application forms may be obtained by writing to the Director, Division of Materials Licensing, U.S. Nuclear Regulatory Commission, Washington, D.C. 20545.

In filing your application, you should submit two copies of Form NRC–313 and two each of the supplemental sheets or other attachments. You should keep at least one complete copy of your application for your files because the license usually requires that you follow the procedures and limitations set forth in the application. It also will come in handy if you need to obtain an amendment to your license at any time and when you apply for renewal. Depending upon the complexity of your proposed operations, you may need to submit comprehensive supplements describing your procedures and other pertinent facts.

The information you give on Form NRC-313 is evaluated by the NRC to determine whether you have the necessary qualifications to conduct your proposed operations in compliance with the Commission's safety standards. While you must state the purpose for which you intend to use radioisotopes, it should be understood that the NRC in issuing a license does not pass upon the technical merit of your project, but is concerned only with its safety—except that in the case of medical uses, radioisotopes are not authorized for routine administration to humans unless it has been demonstrated through research that they are likely to accomplish the desired results. Applications for nonroutine medical uses of radioisotopes are reviewed by the Commission's Advisory Committee on Medical Uses of Isotopes.

The NRC's safety evaluation of your application is made on the basis of your training and experience and the instrumentation, equipment, facilities and procedures you propose to use for radiation protection and waste disposal. It is important, therefore, for you to present the required information accurately, clearly, and completely. If your employees are to handle radioisotopes, they must also have adequate training and experience, and this must be shown in the application. In some cases a member of the NRC regulatory staff may visit an applicant's plant or laboratory before action is taken on his application.

Training[3] in basic radioisotope handling techniques should include training in (a) the principles and practices of radiation safety; (b) radioactivity measurements, standardization and monitoring techniques and instruments, (c) mathematics and calculations basic to the use and measurement of radioactivity; (d) biological effects of radiation; and (e) the handling or use of radioisotopes commensurate with the types and quantities to be employed in the program. The extent of experience and training required is based upon the nature and complexity of a given program.

The application must include your name and address and give detailed information on the quantity, type, and chemical or physical form of radioisotopes to be used, and the purpose for which radioisotopes will be used.

B. Special Licensing Guides

To meet problems peculiar to certain categories of radioisotope use, the NRC has prepared special licensing guides to assist applicants for licenses in these fields. A prospective user of radioisotopes in any of these categories should obtain the appropriate NRC licensing guide and follow its instructions carefully in preparing his application. He may have to use a special application form, which will be indicated in the particular licensing guide dealing with his field of interest.

Single copies of these special guides may be obtained at no charge by writing to the Director, Division of Materials Licensing, U.S. Nuclear Regulatory Commission, Washington, D.C. 20545. The titles are:

"NRC Licensing Guide—Medical Programs"

"NRC Licensing Guide—Industrial Radiography"

"NRC Licensing Guide—Teletherapy Programs"

[3] Training may be obtained by attending college or university courses or short courses sponsored by the Bureau of Radiological Health, HEW, Rockville, Maryland 20850 or Special Training Division, Oak Ridge Associated Universities, P.O. Box 117, Oak Ridge, Tennessee 37830. Courses in the use and operation of industrial gauges or radiography equipment are available from companies which distribute this equipment.

C. The License and Its Provisions

If your application is approved, the Commission will issue you a Byproduct Material License, Form NRC-374. As a licensee, you must confine your possession and use of radioisotopes to the locations and purposes authorized in the license. Authorization of locations and purposes, however, may be quite broad, depending on the needs of the licensee. For example, locations authorized by an NRC license may be anywhere in the United States (except Agreement States), if circumstances warrant.

Your license carries with it, unless otherwise provided, the right to receive, acquire, own and import radioisotopes and to transfer them to other NRC or State licensees authorized to receive them. Exports of radioisotopes by licensees are subject to certain restrictions set forth in the regulations.

The Commission may incorporate in any license additional requirements or conditions deemed appropriate or necessary to public health and safety or to the national security. (A sample license is reproduced as Appendix F.)

D. Special License Conditions

Since there is such a wide range in the kinds of radioisotopes, their uses, and the quantities involved, individual license applications occasionally present unusual considerations that require specialized licenses covering circumstances not contemplated in the regulations. In such cases, the Commission may include in a particular license specific requirements covering those matters not expressly defined in the regulations. If, after a license is issued, it is found that some aspect of the licensee's activity has not been appropriately covered by the regulations or by the conditions in the license, the Commission may issue an order imposing additional requirements upon the licensee. On the other hand, a licensee may request amendment of his license to change or eliminate a condition when he feels his operations warrant such consideration.

E. Expiration and Renewal

The term of a license for radioisotopes may be from two to five years, depending on the nature of the licensed activity. The expiration date of a license should be carefully noted. *When a licensee has filed an application for license renewal 30 days or more before its expiration, the existing license does not expire until the new application has been finally acted upon by the Commission.*

An application for renewal of a license should be filed on Form NRC-313 under the same procedure as that for the existing license. Information contained in previous applications, statements or reports may be incorporated in the renewal application by reference, provided that such references are clear and specific.

F. Amendments to Licenses

Application for amendment of an existing license should be filed on Form NRC-313 under the same procedure as that for a new license, except that it is not ordinarily necessary to submit a completely new application. In applying for an amendment, a licensee should specify how he desires his license to be amended and the reasons for amending it, such as the need for additional radioisotopes, increased quantities, or the like.

G. License Fees

The Commission's regulations in 10 CFR Part 170 establish fees for certain types of licenses. Fees are charged for only two types of byproduct material (radioisotope) licenses—licenses which authorize the possession and use of 100,000 curies or more in sealed sources used for irradiation of materials, and licenses which authorize the receipt of waste materials from other persons for the purpose of commercial disposal by the waste disposal licensee. The Commission is continuing to study the subject of fees for materials licenses not covered by the current schedule in § 170.31 of 10 CFR Part 170.

Section VI

WITH A LICENSE GOES RESPONSIBILITY

While the NRC decides that an applicant is properly qualified to use radioisotopes safely by virtue of training and experience, facilities and equipment, and operating procedures, these qualifications do not in themselves assure safe use. The NRC relies on licensee management to see that employees use radioisotopes safely and in accordance with the requirements of the license and the regulations.

Maintaining radiation safety requires responsible planning, supervision and adherence to safe practices on the part of the licensee. Operational safety is governed by two factors. The first consists of the material, equipment and procedures used. The second consists of the persons who use the material and equipment, which includes maintaining sufficiently trained personnel. Both factors are under the control of the licensee. Operational safety, therefore, is his responsibility. Periodic checks to see that employees are following management's instructions and radiation safety rules are essential in maintaining safe operations.

Commission regulations require licensees to maintain certain records concerning their program. Management should give particular attention to establishing a system of records covering the receipt, transfer, export, and disposal of radioisotopes; radiation exposure of persons working in the program, and surveys made to evaluate radiation safety.

Appendix E

Form NRC-313b(I)
(8-64)

UNITED STATES
NUCLEAR REGULATORY COMMISSION

INSTRUCTIONS FOR PREPARATION OF APPLICATION FOR BYPRODUCT MATERIAL LICENSE FORM NRC-313 and 313a

GENERAL INFORMATION

An applicant for a "Byproduct Material (Radioisotopes) License" should complete Form NRC-313 in detail and submit in duplicate to the United States Nuclear Regulator Commission. The applicant should endeavor to cover his entire radioisotope program with one application, if possible. However, separate applications should be submitted for medical teletherapy and gamma irradiators. Supplemental sheets may be appended when necessary to provide complete information. *Item 16 must be completed on all applications. Submission of an incomplete application will often result in a delay in issuance of the license because of the correspondence necessary to obtain information requested on the application.*

NOTE.—When the application includes one of the special uses listed below, the applicant should request the appropriate pamphlet which provides additional instructions:

1 Industrial Radiography—"Licensing Requirements for Industrial Radiography" (use application FORM NRC-313R for Radiography);

2 Teletherapy—"Licensing Requirements for Teletherapy Programs;"

3 Broad License (research and development)—"Licensing Requirements for Broad Licenses for Research and Development;" and

4 Broad License (medical uses)—"Licensing Requirements for Broad Medical Use."

The Form NRC-313a should be completed in detail each time a medical request is made for a human use of radioisotopes. Two copies of the completed Form NRC-313 and 313a (if a medical application) and two copies of each enclosure thereto, should be sent to the U.S. Nuclear Regulatory Commission, Division of Materials Licensing, Washington, D.C., 20545. One copy should be retained for the applicant's file.

EXPLANATION OF FORM NRC-313

Item No.

1 (*a*) The "applicant" is the organization or person legally responsible for possession and use of the byproduct material specified in the application.

(*b*) Indicate other address(es) at which byproduct material will be used, if different from that listed in 1(*a*). A post office box number is not acceptable.

2 The "department" is the department or similar subdivision where the byproduct material will be used.

3 Self-explanatory.

4 The "individual user" is the person experienced in use and safe handling of radioisotopes. *If the application is for "human use," the individual user must be a physician licensed by a State or Territory of the United States to dispense drugs in the practice of medicine and have extensive experience for each proposed clinical use.*

5 Self-explanatory.

6 (*a*) List by name each radioisotope desired, such as "Carbon 14," "Cobalt 60," etc.

(*b*) List chemical and/or physical form for *each* radioisotope and the quantity of *each* which the applicant desires to possess at any one time. If more than one chemical or physical form of a particular radioisotope is desired, a *separate* possession limit should be stated for each form. For example, an applicant desiring to use two chemical forms of Iodine 131 must specify both forms and a possession limit for *each* form. Example:

Iodine 131	Iodide	10 millicuries
Iodine 131	Iodinated Human Serum Albumin	1 millicurie
Krypton 85	Gas	1000 millicuries

If the byproduct material is to be obtained as a sealed source(s), specify the manufacturer, model number, and amount of activity in *each* sealed source. Example:

Cobalt 60	3 Sealed Sources, 100 mc each (Iso Corp. Model Z-54)	300 millicuries

7 State the use of each byproduct material and chemical form specified in Item 6(*a*) and (*b*). If the radioisotope is for "human use," *do not complete this item; complete Form NRC-313a, Supplement A—Human Use.*

8-9 These items must be completed for *each* individual named in Item 4. If more than one individual is listed in Item 4, clearly key the name of each individual to his experience.

10-16 Self-explanatory.

Appendix E—*Continued*

EXPLANATION OF FORM NRC-313e—SUPPLEMENT A—HUMAN USE

Item No.

1 Self-explanatory.

2 Self-explanatory.

3 Federal Regulations provide that the using physician have substantial experience in the proposed use, the handling and administration of radioisotopes and, where applicable, the clinical management of radioactive patients. The physician must furnish suitable evidence of such experience with his application. Supplement A—Human Use—Page 3 is provided for conveniently presenting these details.

4 Name or describe each clinical use for each radioisotope and chemical form administered. List radiological protection procedures to be followed in sufficient detail to permit a realistic evaluation of the potential radiological hazards.

5 (*a*) Dosage for treatment of patients will depend upon the clinical judgment of the responsible physician; the NRC is only interested in the *proposed dosage range*.

(*b*) For experimental programs or new and unusual uses, the maximum single dose of radiomaterial to be administered should be included and the approximate number and frequency of such doses. Rationale for unusually high dosages should be presented. The proposed use should be outlined in detail demonstrating that radiological health safety to the patient will not be jeopardized. If the use duplicates, or is based on, a use reported in the technical literature, an abstract of such a report or article and a brief statement as to how such use will be followed or modified will suffice.

6 Radioisotopes furnished by NRC facilities are pharmaceutically UNREFINED. An applicant should include information regarding processing or standardization procedure if byproduct material will not be obtained in precalibrated form for oral administration or precalibrated and sterilized form for parenteral administration.

7 Self-explanatory.

8 (*a*) Give the name and address(es) of the hospital(s) which will admit your patients that have been administered radioisotopes.

(*b*) Submit in duplicate a copy of the radiological protection instructions furnished to the hospital personnel regarding the care of patients to whom radioisotopes have been administered. Attach also a list of radiation instruments you will make available to the hospital.

9 (*a*), (*b*) To be completed by using physician.

10, 11, 12 It is recommended that these items be completed by the applicant physician's preceptor in the medical use of radioisotopes. The preceptoring physician is usually the chairman of the medical isotopes committee of the institution where clinical experience was acquired. However, the preceptor may be a staff physician experienced in the clinical use of radioisotopes under whom the using physician's radioisotope training and experience was acquired. If possible, the using physician's entire clinical radioisotope experience should be included. Additional comments may be presented in the space provided on page 4.

NOTE.—*For Medical-Institutional Type Program*

1 List the names, medical specialties, and radioisotope experience, if any, of each member of the local isotope committee.

2 State the procedures the local isotope committee will use to control the procurement and to approve uses of radioisotopes at the institution.

3 Submit a copy of instructions given to nurses who will care for patients containing byproduct material.

4 Submit a copy of radiological protection rules and procedures given to individuals using radioisotopes at the institution.

Appendix E—Continued

Page Two

TRAINING AND EXPERIENCE OF EACH INDIVIDUAL NAMED IN ITEM 4 (Use supplemental sheets if necessary)

8. TYPE OF TRAINING	WHERE TRAINED	DURATION OF TRAINING	ON THE JOB (Circle answer)	FORMAL COURSE (Circle answer)
a. Principles and practices of radiation protection	Univ. of Michigan - Ann Arbor and	1 year	Yes No	Yes No
b. Radioactivity measurement standardization and monitoring techniques and instruments	Oak Ridge Institute of Nuclear Studies - Oak Ridge, Tennessee (both courses covered subjects)	6 weeks	Yes No	Yes No
c. Mathematics and calculations basic to the use and measurement of radioactivity			Yes No	Yes No
d. Biological effects of radiation			Yes No	Yes No

9. EXPERIENCE WITH RADIATION (Actual use of radioisotopes or equivalent experience)

ISOTOPE	MAXIMUM AMOUNT	WHERE EXPERIENCE WAS GAINED	DURATION OF EXPERIENCE	TYPE OF USE
I-131	30 mc	University of Michigan	1 year	Research and Teaching
P-32	50 mc	" " "	"	Plant Metabolism
Cs-137	1 mc	" " "	"	Synthesis - labeled compounds
C-14	100 uc	ORINS	2 weeks	Animal Experiments

10 RADIATION DETECTION INSTRUMENTS (Use supplemental sheets if necessary)

TYPE OF INSTRUMENTS (Include make and model number of each)	NUMBER AVAILABLE	RADIATION DETECTED	SENSITIVITY RANGE (mr/hr)	WINDOW THICKNESS (mg/cm.)	USE (Monitoring, surveying, measuring)
Mica Instr. Co. Model 2 Scaler & Model 3 Gas Flow Counter	1 each	beta-gamma	--	--	Measuring
Mica Model 1 Scintillation Counter	1	beta-gamma	--	--	Measuring
Ace Instr. Co. Model H. GM Survey Meter	1	beta-gamma	0-50 mr/hr	2 $\frac{mg}{cm^2}$	Survey

11 METHOD, FREQUENCY, AND STANDARDS USED IN CALIBRATING INSTRUMENTS LISTED ABOVE Survey instrument calibrated every 6 months with Co 60 standard. Measuring instruments checked as needed using reference sources from National Bureau of Standards.

12 FILM BADGES, DOSIMETERS, AND BIO-ASSAY PROCEDURES USED (For film badges, specify method of calibrating and processing, or name of supplier)

Film badge service from Johnson Co. on a monthly basis.

INFORMATION TO BE SUBMITTED ON ADDITIONAL SHEETS IN DUPLICATE

13 FACILITIES AND EQUIPMENT Describe laboratory facilities and remote handling equipment, storage containers, shielding, fume hoods, etc. Explanatory sketch of facility is attached (Circle answer) Yes No

See Attachment

14 RADIATION PROTECTION PROGRAM Describe the radiation protection program including control measures. If application covers sealed sources, submit leak testing procedures where applicable, name, training, and experience of person to perform leak tests, and arrangements for performing initial radiation survey, servicing, maintenance and repair of the source

See Attachment

15 WASTE DISPOSAL If a commercial waste disposal service is employed, specify name of company. Otherwise, submit detailed description of methods which will be used for disposing of radioactive wastes and estimates of the type and amount of activity involved. See Attachment

Decay or transfer to authorized recipients.

CERTIFICATE (This item must be completed by applicant)

16. THE APPLICANT AND ANY OFFICIAL EXECUTING THIS CERTIFICATE ON BEHALF OF THE APPLICANT NAMED IN ITEM 1, CERTIFY THAT THIS APPLICATION IS PREPARED IN CONFORMITY WITH TITLE 10, CODE OF FEDERAL REGULATIONS, PART 30 AND THAT ALL INFORMATION CONTAINED HEREIN, INCLUDING ANY SUPPLEMENTS ATTACHED HERETO, IS TRUE AND CORRECT TO THE BEST OF OUR KNOWLEDGE AND BELIEF

National Foundation for Research

Applicant named in item 1

Date March 31, 1967

By David A. Gaunt

David A. Gaunt

Director of Research

Title of certifying official

WARNING.—18 U.S.C., Section 1001; Act of June 25, 1948, 62 Stat. 749, makes it a criminal offense to make a willfully false statement or representation to any department or agency of the United States as to any matter within its jurisdiction

Appendix E—Continued

Form NRC 313 (8-64) 10 CFR 30	UNITED STATES NUCLEAR REGULATORY COMMISSION **APPLICATION FOR BYPRODUCT MATERIAL LICENSE**	Form approved. Budget Bureau No. 38-R027

INSTRUCTIONS.—Complete items 1 through 16 if this is an initial application for renewal of a license. Information contained in previous applications filed with the Commission with respect to items 8 through 15 may be incorporated by reference provided references are clear and specific. Use supplemental sheets where necessary. Item 16 must be completed on all applications. Mail two copies to. U.S. Nuclear Regulatory Commission, Washington, D.C., 20545, Attention. Isotopes Branch, Division of Materials Licensing. Upon approval of this application, the applicant will receive an NRC Byproduct Material License. An NRC Byproduct Material License is issued in accordance with the general requirements contained in Title 10, Code of Federal Regulations, Part 30, and the License is subject to Title 10, Code of Federal Regulations, Part 20.

1. (a) NAME AND STREET ADDRESS OF APPLICANT (Institution, firm, hospital person, etc. Include ZIP Code.)	(b) STREET ADDRESS(ES) AT WHICH BYPRODUCT MATERIAL WILL BE USED (If different from 1(a). Include ZIP Code.)
National Foundation for Research 2042 Grand Avenue Anderson, Indiana	Same
2. DEPARTMENT TO USE BYPRODUCT MATERIAL	3. PREVIOUS LICENSE NUMBER(S) (If this is an application for renewal of a license, please indicate and give number.)
Radioisotope	None
4. INDIVIDUAL USER(S) (Name and title of individual(s) who will use or directly supervise use of byproduct material. Give training and experience in Items 8 and 9.)	5. RADIATION PROTECTION OFFICER (Name of person designated as radiation protection officer if other than individual user. Attach resume of his training and experience as in Items 8 and 9.)
Chesteen Craig	Same as user

6. (a) BYPRODUCT MATERIAL (Elements and mass number of each)	(b) CHEMICAL AND/OR PHYSICAL FORM AND MAXIMUM NUMBER OF MILLICURIES OF EACH CHEMICAL AND/OR PHYSICAL FORM THAT YOU WILL POSSESS AT ANY ONE TIME (If sealed source(s), also state name of manufacturer, model number, number of sources and maximum activity per source.)
A. Carbon 14	A. Any - 100 millicuries
B. Iodine 131	B. Any - 50 millicuries
C. Phosphorus 32	C. Any - 50 millicuries
D. Cobalt 60	D. Sealed Reference Source (Acme Co. Model R-1) - 5 millicuries
E. Hydrogen 3	E. Tritium Foil (A&M Corp. Model 508) - 200 millicuries

7. DESCRIBE PURPOSE FOR WHICH BYPRODUCT MATERIAL WILL BE USED. (If byproduct material is for "human use," supplement A (Form NRC-313a) must be completed in lieu of this item. If byproduct material is in the form of a sealed source, include the make and model number of the container and/or device in which the source will be stored and/or used.)

A. through C. Laboratory studies in animals. Chemical synthesis of labeled compounds.
D. Instrument calibration.
E. For use in A&M Corp. Model 5120 detector cell used in a gas chromatograph.

Appendix E—Continued

SAMPLE APPLICATION

FORM NRC-313

Item 13

All isotopes are received and stored in the Radioisotope Laboratory. This facility is equipped with lead storage containers, portable lead bricks for shielding, remote handling tongs, work benches, sinks, trays, waste containers, and similar equipment. See attached sketch of layout. The counting room next door contains the measuring instruments and the room is equipped with table, laboratory bench, sink, and waste container. See attached sheet for animal uses.

Item 14 and Item 15

All isotopes must be procured by the purchasing office upon approval of the Director of Research.

Isotopes will be stored in a locked storage container in the Radioisotope Laboratory. Only persons under the supervision of the responsible user shall have access to the materials.

Weekly surveys will be made with a GM survey meter in all areas where isotopes are handled, stored, or dispensed. Chemical synthesis of labeled compounds or any handling of bulk radioisotopes will be confined to the radiochemical hood using appropriate shielding to reduce radiation levels. Laboratory coats and rubber gloves will be worn when processing loose materials or handling contaminated articles.

All repair and maintenance of sealed sources will be performed by the X Company. The responsible user will leak test the sealed source by using a dampened cotton swab held by tweezers while the source rests in the recess of its storage container. The test sample will be counted in the gas flow counter.

PROCEDURES FOR USE OF BYPRODUCT MATERIAL IN ANIMAL RESEARCH PROGRAMS

All samples of byproduct material to be administered to animals will be prepared in the Radioisotopes Laboratory on easily decontaminated surfaces or in a ventilated hood if necessary. Rubber gloves and laboratory coats will be worn by personnel during these preparations. Remote handling tools are available and will be used when necessary. All pipetting of radioactive material will be performed with a remote pipetting device.

Experimental animals will be caged in a room below the Radioisotope Laboratory. The animals will be injected with byproduct materials either in the animal room or the Radioisotope Laboratory. The animals will remain in cages until their excretions contain only background amounts of byproduct material, or until they are sacrificed.

The excreta from the animals will be disposed of into the sanitary sewer in concentrations not exceeding those specified in Section 20.303 of 10 CFR 20, with a total disposal not to exceed 1 curie per year.

All dry byproduct material waste will be deposited in properly labeled metal cans provided in the laboratory and animal room. The cans will be lined with disposable polyethylene bags. Short-lived waste will be stored until it emits only background levels of radiation as measured with a survey meter at contact. The waste will then be disposed of in normal trash after all labels denoting radioactivity have been removed.

Appendix E—*Continued*

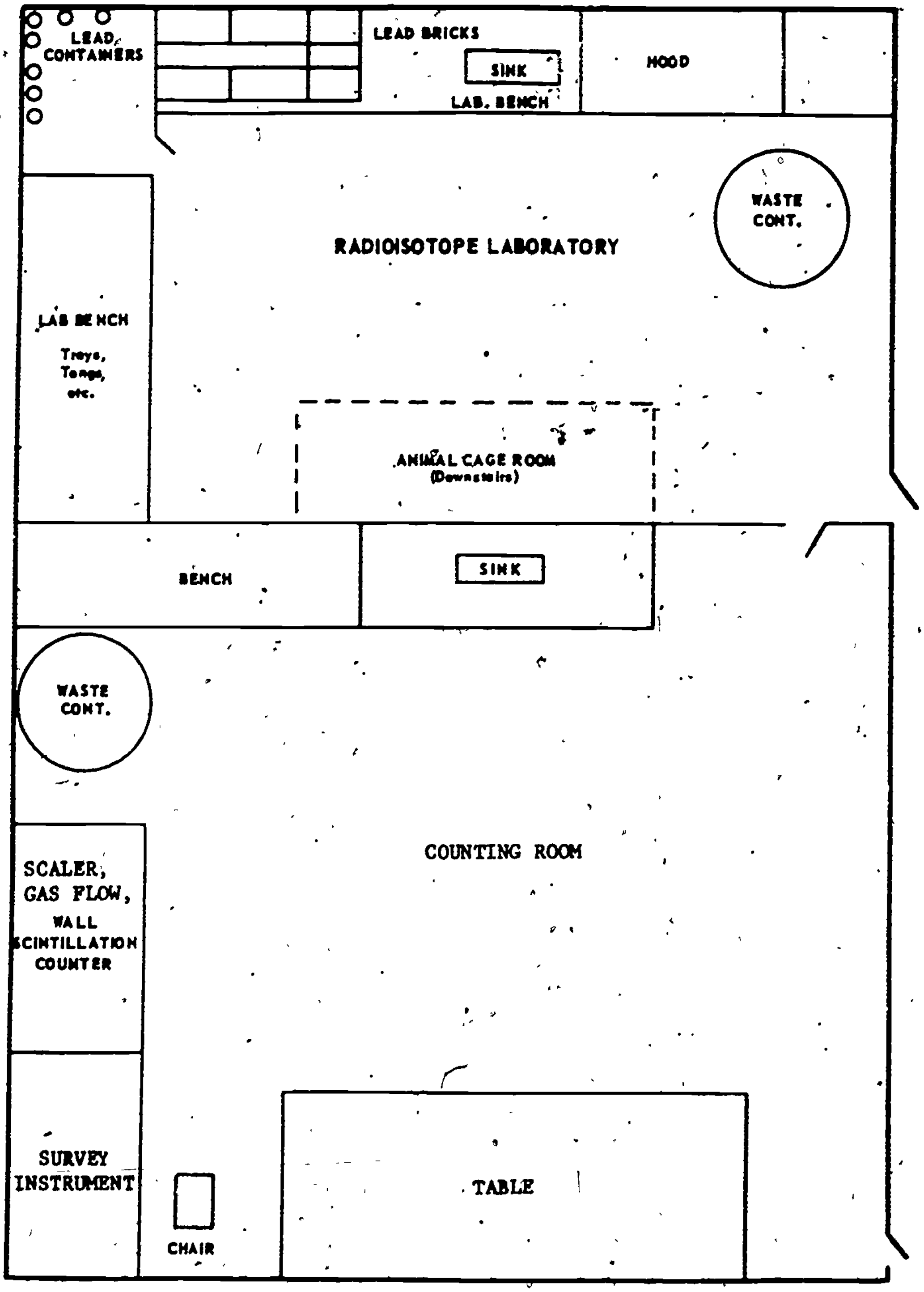
Sacrificed animals containing short-lived byproduct material will be stored in a freezer until the radioactivity has decayed to background and then they will be disposed of in normal trash. Solid long-lived wastes will be disposed of through a licensed commercial waste disposal company.

Animal cages will be decontaminated with detergent and scrub brushes. Laboratory coats and rubber gloves will be worn by personnel. Contaminated water will be flushed down the sink or floor drains in the animal room.

The animal room and laboratory will be surveyed for contamination and radiation levels after each preparation and/or administration of radioisotope(s). The animal room will be locked unless attended by an authorized user of byproduct material.

Appendix E—Continued

SAMPLE APPLICATION



AIR SAMPLING

DF380, AIR SAMPLING

A. Air Sampling.

1. Gaseous Pollutants.

Gaseous pollutants may be sampled by monitoring the atmosphere with a special gas monitoring instrument such as the T-290 (used for tritium monitoring) or by adsorbing, absorbing, freezing out, condensing or grabbing a sample of the atmosphere or environment and counting it on an appropriate instrument. In the latter techniques the volume of the sample must be considered.

2. Particulate Pollutants.

Particulate pollutants exist as small particles of dust or debris suspended in the air. They may be retained within the respiratory tract if inhaled. The most common method of sampling for these particles is filtration. Necessary apparatus may be broken into three general groups: air mover, filtration medium, air flow measuring device.

a. Air Mover.

The air mover is a mechanical device which draws or pushes air through the filtration medium. A vacuum cleaner would make an adequate high volume air mover. Commonly used air movers are manufactured under the trade names of "Staplex" and "Gelsen."

b. Filtration Medium.

The filtration medium may be cellulose filter paper, inorganic fibrous mat, felt, dry gel filter, or any other suitable material. It should be capable of trapping and retaining the majority of particles existing as contamination and yet it should not greatly reduce the flow of air through the system. The most commonly used filter media are fiber glass mats and filter paper. When sampling is complete the filter is removed from the sampler and the quantity of contaminant determined on an appropriate instrument.

c. Air Flow Measuring Device.

In order to determine the concentration of contaminants in the air it is necessary to know the volume of air sampled. A conventional device for determining air flow is an air flow meter or "visifloat." These are an integral part of most commercial samplers. The flow meters are calibrated in cubic feet per minute. The total volume is the flow rate times the time of the sample.

B. Calculation.

1. There are always naturally occurring isotopes present in the environment. Radon (^{222}Rn) and Thoron (^{220}Rn), are naturally occurring radioactive gaseous descendant products of Uranium 238 and Thorium 232. They, along with their daughter products are found throughout the earth's atmosphere. One must always consider these when determining the airborne contamination.

2. Assuming that the man-made contamination is long-lived, the counts due to radioisotopes on the filter at any time after sampling has been stopped may be represented by the expression

$$C = C_{LL} + C_{Tn}e^{-\lambda_{Tn}t} + C_{Rn}^{-\lambda_{Rn}t}$$

where C_{LL} = counts due to the long-lived isotope

C_{Tn} = counts due to thoron at time sampling stopped

C_{Rn} = counts due to radon at time sampling stopped

λ_{Tn} = decay constant of thoron series

λ_{Rn} = decay constant of radon series

t = time after stopping of air sample at which count is taken.

The radon decay series decays to an insignificant amount of radioactivity 4 hours after the sampling is stopped ($t_{1/2}$ = 30 min).

and $C_1 = C_{LL} + C_{Tn}e^{-\lambda_{Tn}t_1}$

where C_1 = a count taken at least 4 hours after the sampling is stopped

t_1 = the time after sampling of count, C_1.

If a second count is taken approximately 20 hours after the initial reading, the number of counts, C_2, is

$$C_2 = C_{LL} + C_{Tn}e^{-\lambda_{Tn}t_2}$$

where t_2 = the time after the sample at which the second count was taken.

By transposing both equations to give an expression for C_{Tn}, equating the resultant expressions and solving for C_{LL} the following expression results.

$$C_{LL} = \frac{C_2 - C_1 e^{-\lambda\Delta t}}{1 - e^{-\lambda\Delta t}}$$

where Δt = difference between t_2 and t_1 $(t_2 - t_1)$.

With this expression and counts taken 4 hours and approximately 24 hours after the sample one can determine the counts due to the long-lived isotope.

The expression may be simplified to

$$C_{LL} = \frac{C_2 - C_1\phi}{1 - \phi}$$

where $\phi = e^{-\lambda\Delta t}$

A table for various t's is included on page 562.

3. To convert counts per minute into disintegrations per minute per milliliter, the following equation is used:

$$d/m\text{-}ml = \frac{cpm(C_{LL})}{V\,(ml) \times E_{ff}(\text{collector}) \times E_{fc}(\text{counter})}$$

Conversion factors from cubic feet to milliliters -

$$(ft^3) \times (2.83 \times 10^4) = ml$$

where d/m-ml = disintegrations per minute per cubic centimeter

cpm = counts per minute due long-lived material

V (ml) = volume of air sampled in cubic centimeters

E_{ff}(collector) = efficiency of collector

E_{fc}(counter) = efficiency of counter (geometry)

4. To convert disintegrations per minute per ml into microcuries per milliliter, the following is used:

$$(d/m\text{-}ml)(4.505 \times 10^{-7}) = \mu Ci/ml$$

where $\mu Ci/ml$ = microcuries per milliliter.

5. The three equations listed above may be combined into one equation, if desired.

$$\mu Ci/ml = \frac{(C_2 - C_1\emptyset)\ (4.505 \times 10^{-7})}{(1 - \emptyset)\ (V_{cm^3} \times E_{ff} \times E_{fc})}$$

NOTE: V is generally expressed in ft^3 so the conversion to cm^3 is $ft^3 \times 2.83 \times 10^4$.

II. Student Performance Objectives.

A. Given standard air sampling equipment, set up and perform routine air sampling operations.

B. Given standard air sampling equipment after routine air sampling operations, safely remove, cut, and prepare the air sample filter for counting.

C. Given the prepared air sample filter properly cut, perform required radiation counting on this filter.

D. Given the counting data from an air sample filter, perform required calculations to determine the long-lived activity.

Table of $e^{-\lambda\Delta t}$ or ϕ

as a Function of Δt

Δt in hours	φ	Δt in hours	φ	Δt in hours	φ
1	.93239	17	.32956	33	.11533
2	.87809	18	.30728	34	.10753
3	.81873	19	.28938	35	.10127
4	.77105	20	.26982	36	.09442
5	.72615	21	.25158	37	.08892
6	.67706	22	.23693	38	.08291
7	.63128	23	.22313	39	.07808
8	.59452	24	.20805	40	.07280
9	.55433	25	.19398	41	.06788
10	.51685	26	.18268	42	.06393
11	.48675	27	.17033	43	.05961
12	.45384	28	.16041	44	.05613
13	.42741	29	.14957	45	.05234
14	.39852	30	.13946	46	.04929
15	.37531	31	.13134	47	.04596
16	.34994	32	.12246	48	.04328

Use λ = 0.0655 (thorium)

Round off exponents to the nearest one hundredth.

III. Problems.

Class and Home Study Problems.

1. An airborne sample gives a count of 403 cpm after 4 hours. At 26 hours the count was 393 cpm. The background count was 3 cpm. The collector was 75% efficient. The volume of air filtered was 6,000 ft^3. The counter was 10% efficient.

   a. What is the airborne concentration of the isotope in μCi/ml?

   b. If the isotope is known to be ^{239}Pu, insoluble, is the concentration within the established limit in a restricted area?

c. If the isotope were ^{233}U, soluble, would the concentration be within the established limit in a restricted area?

2. An airborne sample gives a count of 41,000 cpm after 4 hours. At 24 hours, the count was 38,400 cpm. The collector is 70% efficient. The counter efficiency is 10% and the background is 100 cpm. The sampler was in operation 5 minutes at a flow rate of 20 cubic feet per minute.

   a. What is the airborne concentration of the isotope in μCi/ml?

b. Could this room be used if the isotope is Tungsten-181, soluble, and the room is unrestricted?

3. A sample of airborne contamination was collected for 2 hours. The sampler filtered 40 cubic feet per minute with 80% efficiency and gave 1050 cpm 4 hours after sampling and 985 cpm 24 hours after sampling. The background was 10 cpm and the counter efficiency was 8%. Further investigation showed that the contamination was a soluble beta emitter with E_{max} at 2.3 Mev and half-life of 61 days. It was found to be Antimony-124.

Is the allowed airborne concentration for this isotope in an unrestricted area exceeded?

4. A sample of airborne contamination was taken using a sampler with the following characteristics: 115 v, .5 amp, 3,000 rpm, 0.5 horsepower. The sample was collected for 1 hour on a Whatman No 41 filter paper disk, 4 inches in diameter. It has been determined that this filter is 90% efficient. The flow meter on the sampler indicated that 21 cubic feet per minute were passing through it. A 2-inch diameter disk of the filter paper, counted 4 hours after sampling, gave a count of 83,466 cpm. After 27 hours, a count of 78,150 cpm was obtained on the same 2-inch disk. Counter efficiency was 5% and background was 36 cpm. It was determined that the contamination was soluble Iodine-131. Does the iodine concentration exceed those for an unrestricted area?

5. Your are on a project in which soluble Manganese-52 dust may become airborne. As a check, you routinely take 1-hour air samples using a sampler which filters 30 cfm with 80% efficiency. You use a counter with 15% efficiency. An activity due to long-lived isotopes greater than a predetermined number of counts per minute indicates a need to restrict the area. What is the predetermined number?

IV. Solutions to Problems.

Solutions to Class and Home Study Problems.

1. a. Determine the counts per minute due to long-lived isotopes, C_{LL}.

$$C_{LL} = \frac{C_2 - (C_1)\phi}{1 - \phi} \qquad C_1 = 403 - 3 = 400$$

$$C_2 = 393 - 3 = 390$$

From Table (page 562) ϕ for Δt of 22 hours, G (26 - 4) is 0.237.

$$C_{LL} = \frac{390 - (0.237)(400)}{1 - 0.237}$$

$$= \frac{390 - 94.8}{0.763}$$

$$= 387 \text{ cpm}$$

Determine the disintegrations per minute, Y, due to the long-lived isotope.

$$Y = \text{d/min-ml} = \frac{C_{LL}}{V \times E_{ff} \times E_{fc}}$$

$$C_{LL} = 387 \text{ cpm}$$

$$V = 6{,}000 \text{ ft}^3$$

$$= 6{,}000 \text{ ft}^3 \times 2.83 \times 10^4 \text{ ml/ft}^3$$

$$E_{ff} = 75\% = 0.75$$

$$E_{fc} = 10\% = 0.10 \text{ c/d}$$

$$Y = \frac{387 \text{ c/m}}{6 \times 10^3 \text{ft}^3 \times 2.83 \times 10^4 \text{ ml/ft}^3 \times 0.75 \times 0.1 \text{ c/d}}$$

$$= \frac{3.87 \times 10^{-3}}{6 \times 2.83 \times 7.5}$$

$$= 3.04 \times 10^{-5} \text{ d/min-ml}$$

Convert disintegrations per milliliter-minute to concentration, Z, in microcuries per milliliter:

$$Z = Y \times 4.505 \times 10^{-7}\ \mu Ci/d/m$$

$$= 3.04 \times 10^{-5}\ d/ml\text{-}min \times 4.505 \times 10^{-7}\ \mu Ci/d/min$$

$$= \underline{\underline{1.37 \times 10^{-11}\ \mu Ci/ml}}$$

b. Look up concentration limits of insoluble ^{239}Pu, for restricted area, in Title 10, Part 20, App B. It is 4×10^{-11}. $1.37 \times 10^{-11}\ \mu Ci/ml$ does not exceed this. <u>It is within established limits</u>.

c. Look up allowable concentration limits for soluble ^{233}U, for restricted area, in Title 10, Part 20, App B. It is $5 \times 10^{-10}\ \mu Ci/ml$. $1.37 \times 10^{-11}\ \mu Ci/ml$ does not exceed this. <u>It is within established limits</u>.

2. a. (1) Determine the counts per minute due to long-lived isotope (C_{LL}).

$$C_{LL} = \frac{C_2 - (C_1)\,\phi}{1 - \phi}$$

$$C_1 = 41{,}000 - 100 = 40{,}900\ \text{cpm}$$

$$C_2 = 38{,}400 - 100 = 38{,}300\ \text{cpm}$$

ϕ for At at 20 hours (24 - 4) is 0.270 (from page 562)

$$C_{LL} = \frac{38{,}300 - (0.270)(40{,}900)}{1 - 0.270}$$

$$= \frac{38{,}300 - 11{,}040}{0.73}$$

$$= 37{,}400\ \text{cpm}$$

(2) Convert the counts per minute detected to disintegrations per milliliter-minute, Y, due to the contamination.

$$Y = \frac{C_{LL}}{V \times E_{ff} \times E_{fc}}$$

$$V = 20 \text{ ft}^3/\text{min} \times 5 \text{ min} \times 2.83 \times 10^4 \text{ ml/ft}^3$$

$$= 2.0 \times 5 \times 2.83 \times 10^5$$

$$= 2.83 \times 10^6 \text{ ml}$$

$$E_{ff} = 70\% = 0.70$$

$$E_{fc} = 10\% = 0.1 \text{ c/d}$$

$$Y = \frac{3.74 \times 10^4 \text{ c/m}}{2.83 \times 10^6 \text{ ml} \times 0.70 \times 0.1 \text{ c/d}}$$

$$= \frac{3.74}{2.83 \times 7.0}$$

$$= 1.89 \times 10^{-1} \text{ d/ml-min}$$

(3) Convert disintegrations per milliliter-minute, Y, to concentration of the contamination in microcuries per milliliter, Z.

$$Z = (4.505 \times 10^{-7} \ \mu\text{Ci/d/min})Y$$

$$= 4.505 \times 10^{-7} \times 1.89 \times 10^{-1}$$

$$= \underline{8.51 \times 10^{-8} \ \mu\text{Ci/ml}}$$

b. Check Title 10, Part 20, App B, to determine the maximum acceptable concentration for soluble Tungsten-181 in an unrestricted area. It is 8×10^{-8} μCi/ml. The determined concentration exceeds this. <u>The room cannot be used.</u>

3. a. Determine the counts per minute due to the long-lived isotope C_{LL}.

$$C_{LL} = \frac{C_2 - (C_1)\,\phi}{1 - \phi}$$

$C_1 = 1050 - 10 = 1040$

$C_2 = 985 - 10 = 975$

ϕ for a Δt of 20 hours (24 - 4) is 0.270 (page 562).

$$C_{LL} = \frac{975 - 281}{0.73}$$

$$= 951 \text{ cpm}$$

b. Convert the counts per minute, C_{LL}, to disintegrations per minute milliliter, Y, due to the long-lived isotope.

$$Y = \frac{C_{LL}}{V \times E_{ff} \times E_{fc}}$$

$$V = 40 \text{ ft}^3/\text{min} \times 2 \text{ hr} \times 60 \text{ min} \times 2.83 \times 10^4 \text{ ml/ft}^3$$

$$= 1.36 \times 10^8 \text{ ml}$$

$$E_{ff} = 80\% = 0.80$$

$$E_{fc} = 8\% = 0.08 \text{ c/d}$$

$$Y = \frac{951 \text{ c/min}}{1.36 \times 10^8 \text{ ml} \times 0.80 \times 0.08 \text{ c/d}}$$

$$= \frac{9.51 \times 10^{-3}}{1.36 \times 8.0 \times 8.0}$$

$$= \underline{1.09 \times 10^{-4} \text{ d/ml-min}}$$

c. Convert the disintegrations per milliliter minute to contamination concentration in terms of microcuries per milliliter, Z.

$$Z = (4.505 \times 10^{-7}\ \mu\text{Ci/d/min})Y$$

$$= 4.505 \times 10^{-7}\ \mu\text{Ci/d/min} \times 1.09 \times 10^{-4} \text{ d/ml-min}$$

$$= 4.91 \times 10^{-11}\ \mu\text{Ci/ml}$$

d. Determine the maximum allowable concentration for soluble ^{124}Sb using Title 10, Part 20, App B. It is 5×10^{-9}. <u>This concentration is not exceeded.</u>

4. a. Determine the number of counts per minute on the 2-inch disc due to long-lived isotopes.

$$C_{LL} = \frac{C_2 - C_1 \phi}{1 - \phi}$$

$$C_1 = 83,466 - 36 = 83,430 \text{ cpm}$$

$$C_2 = 78,150 - 36 = 78,114 \text{ cpm}$$

ϕ for a Δt of 23 hours (27 - 4) is 0.223 (from page 563).

$$C_{LL} = \frac{78,114 - (83,430)(0.223)}{(1 - 0.223)}$$

$$= \frac{78,100 - 18,600}{0.777} \text{ (using 3 significant figures)}$$

$$= \underline{76,600 \text{ cpm}}$$

b. Determine the number of counts per minute on the whole 4-inch filter.

$$C_{LL-4} = C_{LL-2} \times \frac{A_4}{A_2}$$

where C_{LL-4} = the cpm on the whole 4-inch filter

C_{LL-2} = the cpm on the 2-inch disk

A_Y = the area of the Y filter = πd^2

$$C_{LL-4} = 76,600 \times \frac{4^2 \pi}{2^2 \pi}$$

$$= 76,600 \times 4$$

$$= 306,400 \text{ cpm}$$

c. Convert the counts per minute of trapped contamination to disintegrations per milliliter-minute in the air, Y.

$$Y = \frac{C_{LL-4}}{V \times E_{ff} \times E_{fc}}$$

$$V = 21\ ft^3/min \times 60\ min \times 2.83 \times 10^4\ ml/ft^3$$

$$= 2.1 \times 6 \times 2.83 \times 10^6$$

$$= 3.56 \times 10^7\ ml$$

$$E_{ff} = 90\% = 0.90$$

$$E_{fc} = 5\% = 0.05\ c/d$$

$$Y = \frac{306,400\ c/min}{3.56 \times 10^7 \times 0.90 \times 0.05\ d/c}$$

$$= \frac{30.64}{3.56 \times 9.0 \times 5.0}$$

$$= 1.91 \times 10^{-1}\ d/ml\text{-}min$$

d. Convert the contamination into terms of microcuries per milliliter, Z.

$$Z = (4.505 \times 10^{-7}\ \mu Ci/d/min)Y$$

$$= 4.505 \times 10^{-7}\ \mu Ci/d/min \times 1.91 \times 10^{-1}\ d/ml\text{-}min$$

$$= \underline{8.61 \times 10^{-8}\ \mu Ci/ml}$$

e. Determine the maximum permissible Iodine-131 concentration for an unrestricted area using Title 10, Part 20, Appendix B.

It is 1×10^{-10}. The concentration in the air exceeds this value.

5. a. Determine the maximum permissible airborne concentration of soluble Manganese-52 for an unrestricted area using Title 10, Part 20, App B. It is 7×10^{-9} µCi/ml.

b. Combining the expression for determining the disintegrations per milliliter minute (Y) from counts per minute due to long lived isotope (C_{LL}), volume of sampled air(V), collector efficiency (E_{ff}), and counter efficiency (E_{fc})

$$Y = \frac{C_{LL}}{V \times E_{ff} \times E_{fc}}$$

and the expression converting disintegrations per milliliter minute (Y) to microcuries per milliliter of airborne contamination (Z)

$$Z = (4.505 \times 10^{-7} \mu Ci/d/m)Y$$

we have an expression for Z in terms of C_{LL}, V, E_{ff}, and E_{fc}.

$$Z = \frac{(4.505 \times 10^{-7} \mu Ci/d/min)C_{LL}}{V \times E_{ff} \times E_{fc}}$$

Rearranging, an expression for C_{LL} is obtained.

$$C_{LL} = \frac{ZVE_{ff}E_{fc}}{4.505 \times 10^{-7} \mu Ci/d/min}$$

Z = the maximum permissible concentration due to the long-lived isotope, ^{52}Mn.

$= 7 \times 10^{-9}$ µCi/ml

$V = 30\ ft^3/min \times 60\ min \times 2.83 \times 10^4\ ml/ft^3$

$= 3 \times 6 \times 2.83 \times 10^6$

$= 5.09 \times 10^7$ ml

$E_{ff} = 80\% = 0.80$

$E_{fc} = 15\% = 0.15$

c. Substituting in the known values

$$C_{LE} = \frac{(7 \times 10^{-9}\ \mu Ci/ml)(5.09 \times 10^{7}\ ml)(0.80)(0.15\ c/d)}{4.505 \times 10^{-7}\ \mu Ci/c/min}$$

$$= \frac{7 \times 5.09 \times 8.0 \times 1.5 \times 10^{3}}{4.505}$$

$$= \underline{94,910\ cpm}$$

A count over 94,910 cpm indicates that the area must be restricted.

DF400

TRANSPORTATION OF RADIOACTIVE MATERIAL

DF400, TRANSPORTATION OF RADIOACTIVE MATERIAL

I. Reference:

The material taught is from R.M. Graziano Tariff 27 and related changes on the DOT regulations and from AR 55-55, "Transportation of Radioactive and Fissile Material Other Than Weapons, dated in 1969. These are the current regulations governing the rights and obligations of those concerned with transportation of radioactive material. There has been a major change in these regulations. Due to the limited number of copies of the R. M. Graziano Tariff Number 27 (with changes), DOT regulations and AR 55-55, there are no student references available; however, the material found in the Vu-Graph handout outlines the material rather thoroughly.

II. Lesson Objectives and Notes.

A. Define terms involved in the Federal law and AR's governing transportation.

B. Define and discuss the grouping of radioactive material for shipment.

C. Explain package requirements.

D. Discuss label requirements for the transport group and quantity shipped and give explanation of the requirements.

E. Explain exemptions to the regulations.

F. Define restrictions on shipment of radioactive materials both in passenger carriers and individual vehicles.

G. Explain the placards required on vehicles and other modes of transportation.

H. Work practical exercise involving transportation problems.

III. List of Vu-Graph Material used in DF400.

1. Radioactive Material.

Any material or combination of material that in any form spontaneously emits ionizing radiation and in which the radioactivity per gram is greater than 0.002 microcurie or greater. In material less than this amount, the radiation must be uniformly distributed if not considered as radioactive.

2. Packaging.

The assembly of the container and any other components necessary to assure compliance with the prescribed packaging requirements.

3. Package.

The packaging plus its content of explosive or other dangerous articles as presented for transportation.

4. Transport Vehicle.

The conveyance used for the transportation of explosives or other dangerous articles including any motor vehicle, rail car or aircraft. Each cargo carrying body (trailer, van, box car, etc) is a separate vehicle.

5. Fissile Radioactive Material.

Fissile radioactive material means the following materials: ^{238}Pu, ^{239}Pu, ^{241}Pu, ^{233}U, ^{235}U or any material containing any of the foregoing materials. Fissile packages are classified according to the control needed to provide criticality safety during transport.

6. Large Quantities of Radioactive Material.

A quantity, the aggregate radioactivity of which exceeds that specified below:

Group I or II	20 Curies
Group III or IV	200 Curies
Group V	5,000 Curies
Group VI or VII	50,000 Curies
Special Form Material	5,000 Curies

7. Normal Form Radioactive Material.

Normal form radioactive material means those which are not special form materials. Normal form materials are grouped into seven transport groups.

8. Special Form Radioactive Materials.

Material, if released from a package, which might present some direct radiation hazard but would present little hazard due to radiotoxicity and little possibility of contamination (may be inherent properties of acquired characteristics, as through encapsulation).

9. Transport Groups.

Transport groups are any one of seven groups into which normal form radionuclides are classified according to their radiotoxicity and their relative potential hazard in transportation.

10. Transport Index.

The number placed on a package to designate the degree of control to be exercised by the carrier during transportation. It is the highest radiation dose rate, in millirem per hour at 3 feet from any accessible external surface. The number expressing the transport index shall be rounded up to the next highest tenth, e.g., 1.01 becomes 1.1.

11. Radiotoxicity.

Radiotoxicity is the potential total effect on the human body due to internal exposure to ionizing radiation presented by a given radio-isotope.

12. Technical Escort.

A group of technically qualified personnel selected to escort a dangerous shipment of materials (radioactive, etc) capable of coping with accidents/incidents while en route to insure maximum safety to personnel and property (private and public).

13. Radionuclides Not in Table.

Radionuclide	Radioactive Half-Life: 0-1,000 Days	Radioactive Half-Life: 1,000 Days to 10^6 Years	Radioactive Half-Life: Over 10^6 Years
Atomic Number 1-81	Group III	Group II	Group III
Atomic Number 82 & Over	Group I	Group I	Group III

14. Mixtures of Radionuclides.

(1) Identity and respective activity of each radionuclide are known, permissible activity of each radionuclide shall be such that the sum, for all groups present, of the ratio between total activity for each group to permissible activity for each group will not be greater than unity.

$$\frac{Ca}{MPCa} + \frac{Cb}{MPCb} + \frac{Cc}{MPCc} \leq 1$$

(2) Group known but amount in each group unknown - mixture assigned to most restrictive group present.

(3) If identity of all or some radionuclides cannot be reasonably determined, each of unidentified radionuclides considered as belonging to most restrictive group which cannot positively be excluded.

(4) Mixture of single radioactive decay chain - nuclides in naturally occurring proportions - considered as single nuclide. Group and activity shall be that of first member unless another member has larger half-life and greater activity, than that member of chain used for group and activity.

15. Type A Package.

(1) Heat - Direct sunlight at an ambient temperature of 130° F in still air.

(2) Cold - ambient temperature of -40° F in still air and shade.

(3) Reduced pressure - ambient atmospheric pressure at 0.5 atmosphere.

(4) Vibration - vibration normally incident to transportation.

(5) Water spray - wetting of package entirely except bottom for 30-minute period. Metal, wood, ceramic, or plastic exempt.

(6) Free drop. Between 1-1/2 and 2-1/2 hours after water spray test, a free drop of 4 feet onto a flat essentially unyielding horizontal surface, striking in a position for which maximum damage is expected.

(7) Corner drop - free drop onto each corner of the package in succession, from a height of 1 foot. Tests are primarily for wood or fiberboard packages and do not exceed 110 pounds in weight for all fissile class II packages.

(8) Penetration - Impact of the hemispherical end of a vertical steel cylinder 1-1/4 inch in diameter and weighing 13 pounds dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture.

(9) Compression - compression load equal to either five times the weight of the package or 2 lb/sq. in. multiplied by the maximum horizontal cross section of the package, whichever is greater. The load shall be applied during a period of 24 hours uniformly against the top and bottom in the position in which the package would normally be transported.

16. Type B Packaging.

Meets conditions for Type A packaging plus:

(1) Reduction of shielding - test will not reduce shielding enough to increase the dose rate at 3 feet from external surface to more than 1,000 mrem/hr.

(2) No radioactive material release - release limited to gases and contaminated coolant containing total radioactivity exceeding neither 0.1% of the total radioactivity of the package contents nor 0.01 curie of group I, 0.5 curie of group II, and 10 curies of groups III and IV, except that in inert gases the limit is 1,000 curies.

(3) Free drop - 30 feet onto a flat essentially unyielding horizontal target surface, striking the surface in a position for which maximum damage is expected.

(4) Puncture - a free drop through a distance of 40 inches striking, in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar. The bar shall be 6 inches in diameter, not less than 8 inches long.

(5) Thermal - radiation environment of 1,475° F for 30 minutes with an emissivity coefficient of 0.9 assuming the surface of the package has an absorption coefficient of 0.8.

(6) Water immersion - (fissile packages only) - under 3 feet of water for a period of not less than 8 hours.

17. Quantity Limitations

Transport Group	Type A Quantity (in curies)	Type B Quantity (in curies)
I	0.001	20
II	0.05	20
III	3	200
IV	20	200
V	20	5,000
VI and VII	1,000	50,000
Special Form	20	5,000

General Packaging Requirements.

a. The outside of each package must incorporate a feature such as seal, which is not readily breakable and which, while intact, will be evidence that the package has not been illicitly opened.

b. Smallest outside dimensions of any package must be 4 inches or greater.

c. Materials packaged in packaging designed to maintain shielding efficiency and leak tightness so that under conditions normally incident to transportation, there will be no release of radioactive material.

d. The packaging must be so designed, constructed and loaded that, when transporting large quantities of radioactive material, heating is not a major factor (122° F on package surface in shade or 180° F at external surface of vehicle on which material is loaded).

e. Enough absorbent material must be provided to absorb at least twice the volume of radioactive liquid contents. Material is outside the shield only if it is shown that if the radioactive contents were taken up by the absorbed material, the resultant dose rate at the surface of the package would not exceed 1,000 millirem/hr.

f. No significant removable radioactive surface contamination.

18. Maximum Dose Rates Allowable.

Sealed Car Shipment - except aircraft:

(1) 1,000 millirem/hr at 3 feet from external surface of the package.

(2) 200 millirem/hr at any point on the external surface of the car or vehicle.

(3) 10 millirem/hr at 6 feet from the external surface of the vehicle.

(4) 2 millirem/hr in normally occupied position in the car or vehicle.

Other Shipment (Compatible Cargo):

200 millirem/hr at any point on the external surface and transport index does not exceed 10. Total transport index/car no greater than 50.

19. Exempt Materials.

Radioactive materials in normal form not exceeding:

Group I	0.01 mCi
Group II	0.1 mCi
Group III, IV, V or VI	1 mCi
Group VII	25 curies
Tritium Oxide in aqueous solution	Concentration not exceeding 0.5 mCi/ml. Total activity per package not more than 3 curies.

Radioactive material in special forms:

Not more than 15 grams of Uranium-235.

Radiation dose rate at any point on the external surface of the package does not exceed 0.5 mrem/hr.

Outside of the inner container must bear the marking "Radioactive."

20. Packaging of Fissile Materials.

a. Fissile Class I - Packages which are nuclearly safe in any number and in any arrangement under all foreseeable circumstances of transport.

b. Fissile Class II - Packages, which in limited number, are nuclearly safe in any arrangement under all foreseeable circumstances of transport.

c. Fissile Class III - Pacakges which are nuclearly safe by reason of special arrangement.

21. Radioactive White I Label.

Dose rate at the external surface of the package does not exceed 0.5 mrem/hr.

Not authorized for Fissile Class II or III.

22. Radioactive Yellow II Label.

Dose rate at the external surface of the package does not exceed 10 mrem/hr and the dose rate does not exceed 0.5 mrem/hr at 3 foot from the external surface of the package.

23. Radioactive Yellow III Label.

(1) Each fissile class III package.

(2) Each package containing a large quantity of radioactive material regardless of dose rates.

(3) Each package requiring special approval (waiver).

(4) Maximum dose rate requirement for material transported without a waiver when shipped with compatible cargo.

(a) 200 mrem/hr at external surface of the package.

(b) 10 millirem/hr at 3 feet from the external surface of the package.

Radioactive labels as outlined above will be affixed to opposite sides of the package (two per package).

24. MIL-STD-1458 dated 11 Dec 1972. Radioactive Materials. Making and labeling of item, package, and shipping containers for identification in use, storage, and transportation.

a. DA Label 135.

b. Radioisotope

c. Activity

d. Date measured.

25. DA Form 2791.

26. Uses of DA Form 2791.

(1) Used for incoming and outgoing shipments.

(2) Accept incoming packages regardless of contamination. Note on this form.

(3) Contamination levels noted for all shipments.

(4) Signed by RPO.

(5) Other forms found in AR 55-55.

27. Contamination Levels.

Curies	dpm	Source
10^{-11} Ci/cm^2	2,200/100 cm^2	Beta-Gamma
10^{-12} Ci/cm^2	220/100 cm^2	Alpha (except natural or depleted U and natural Th)

Contaminant known to be natural or depleted U or natural Th.

10^{-10} Ci/cm^2	22,000/100 cm^2	Beta-Gamma
10^{-11} Ci/cm^2	2,200/100 cm^2	Alpha

Non-closed vehicles - Dose rate of fixed contamination not greater than 0.5 mrem/hr.

Closed Vehicles - vehicle kept closed at all times except load. Dose rate of fixed contamination not greater than 10 mrem/hr at interior surface or 2 mrem/hr at 3 feet from any interior surface. Vehicle stenciled: "For Radioactive Material Use Only" - letters 3 inches high on both sides of outside of the vehicle.

28. Shipping Papers.

(1) Exempt quantity for labeling - indicate by words "No Label Required" immediately following description on shipping papers.

(2) Transport Group or Groups of the radionuclides if the material is in normal form.

(3) Name of the radionuclides and description of physical and chemical form if material is in normal form.

(4) Activity of the radioactive material in curies.

(5) Type of label applied to the package.

(6) For fissile radioactive material, fissile class of the package, and weight in grams or kilograms of fissile isotope.

(7) For export - a copy of any special permit issued by DOT for the package.

29.

Total Transport Index	Minimum Separation Distance in Feet to Nearest Undeveloped Film	Minimum distance in Feet to Area of Persons or Minimum distance in Feet from Dividing Partition for Combination Car
None	0	0
0.1 - 10.0	15	3
10.1 - 20.0	22	4
20.1 - 30.0	29	5
30.1 - 40.0	33	6
40.1 - 50.0	36	7

30.

Total Transport Index	Minimum Separation Distance in Feet to Nearest Undeveloped Film for Various Times of Transit: Up to 2 Hours	2 - 4 Hours	4 - 8 Hours	8 - 12 Hours	Over 12 Hours	Minimum Distance in Feet to Area of Persons, or Minimum Distance in Feet from Dividing Partition of Cargo Compartment
None	0	0	0	0	0	0
0.1 - 1.0	1	2	3	4	5	1
1.1 - 5.0	3	4	6	8	11	2
5.1 - 10.0	4	6	9	11	15	3
10.1 - 20.0	5	8	12	16	22	4
20.1 - 30.0	7	10	15	20	29	5
30.1 - 40.0	8	11	17	22	33	6
40.1 - 50.0	9	12	19	24	36	7

31. Movement by Military Vehicle.

(1) Comply with distance tables for undeveloped film and persons.

(2) On-site movement - not packaged or labeled - moved under proper supervision.

(3) Arranged by the Transportation Officer.

(4) Drivers briefed - Yellow II and Yellow III labels.

(5) Driver has copy of shipping papers.

(6) Escort commanders - copy of written instructions.

(7) Drivers supplied with written instructions.

(8) Only shipments requiring special approval need further restrictions than those listed.

32. Written Instructions.

WARNING

THIS VEHICLE IS CARRYING RADIOACTIVE MATERIALS

When undamaged, the package(s) (is, are) safe to handle for short periods of time. In case of accident, notify

____

33. Rail Placard.

34. Motor Vehicle Placard.

a. Placard must be used for any Yellow III label material or for carload of material.

b. Placed in front, back, and both sides of vehicle.

c. Must have "Radioactive" - letters 4 inches high as a minimum and at least a 1-inch border.

d. Must be black letters on a yellow background.

IV. Example Problems of Packaging and Labeling Radioactive Materials.

1. Example Problem No. 1.

a. As radiological Safety Officer, you have been asked to procure a container to ship 1 curie of Tellurium-121 (^{121}Te) encapsulated pellets. Since this is a gamma emitter only, you decide to use lead as the inner container. How much lead is required in the inner container if the overall package is found to be 1 square meter? Assume inner package is to be placed in the center of the outer package. What transport group would the material fall under? What type of package would be required? What type of label would be required?

Neglect dose buildup.

b. Solution.

(1) (a) In checking the table on transport groups, ^{121}Te is not listed, so we are required to go to the exception. We find the Atomic Number is between 1-81 and the half-life of each is less than 1,000 days (17 d for ^{121}Te). Therefore, it is a group III item.

(b) In checking the quantities for group III items, we find Type A packages can hold up to 3 curies and Type B packages can hold up to 200 curies. Since we have 1 curie, it would be most economical to use Type A packaging. Type B could also be used since Type B would also meet the necessary requirements.

(c) Since large quantities of radioactive material require a radioactive yellow III label, check this item. For group III materials, this is 200 curies so it is not classified as a large quantity.

(d) It is an encapsulated source, so it could also fall under special form which allows 20 curies for Type A packages but the degree of encapsulation is unknown so it is a normal form material.

(e) Checking the exempt quantities, we find group III materials listed as 1 mCi, therefore it is not exempt.

(2) On the labels you have three choices dependent on the dose rate. DA Label 15 must be used.

White I Label	Surface dose rate not exceeding 0.5 mrem/hr.
Yellow II Label	Surface dose rate not exceeding 10 mrem/hr; dose rate at 3 feet not exceeding 0.5 mrem/hr.
Yellow III Label	Surface dose rate not exceeding 200 mrem/hr; dose rate at 3 feet not exceeding 10 mrem/hr.

If these dose rates for yellow III are exceeded, then a waiver must be obtained. Waivers are to be avoided if possible. Since the shielding required would be much less, it will probably be sent yellow III label and with a DA Label 15.

(3) $\underline{^{121}Te}$

$S = 0.56\ n\ Ci\ E$

$S = 0.56 \times (0.18) \times 1 \times 0.508$

$S = 0.051$ rhm

$S = 0.56\ n\ Ci\ E$

$S = 0.56 \times 0.80 \times 1 \times 0.573$

$S = 0.257$ rhm

Total rhm

$S = 0.051$ rhm $+ 0.257$ rhm $= 0.308$ rhm

(4) Find R.

$$R = \frac{S}{d^2} = \frac{0.308}{(0.5)^2} = \frac{0.308}{0.25}$$

$R = 1.232$ rad/hr at 0.5 meter or at the surface of the container.

(5) Calculate the lead needed to reduce the dose rate.

$R_o = 1.232$ rad/hr $\qquad \mu/\rho$ for 0.5 Mev $= 0.161$

$R = 200$ mrad/hr $\qquad \mu/\rho$ for 0.6 Mev $= \underline{0.125}$

$\qquad\qquad\qquad\qquad\qquad\qquad 0.036$

$$\therefore 0.036 \times \frac{73}{100} = 0.036 \times 0.73 = 0.026$$

$$\begin{array}{r} 0.161 \\ -0.026 \\ \hline 0.135 \end{array}$$

μ/ρ of 0.573 Mev gamma $= 0.135$

$\mu = \mu/\rho \times (\rho) = 0.133 \times 11.342$

$\mu = 1.51\ cm^{-1}$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{1.51} = 0.46 \text{ cm}$$

$$2^n = \frac{R_o}{R}$$

$$2^n = \frac{1232}{200}$$

$$2^n = 6.16$$

$n = 2.7$ using the 2^n table

$$n = \frac{X}{X_{\frac{1}{2}}}$$

$$2.7 = \frac{X}{0.46}$$

$$X = 1.195 \text{ cm}$$

(6) For a reading at 1 meter:

$S = 0.308$ rhm $\qquad R = \frac{S}{d^2}$

$d = 1.5$ meters $\qquad R = \frac{0.308}{(1.5)^2} = \frac{0.308}{2.25}$

$R = 0.137$ rad/hr or 137 mrad/hr at 1.5 meters.

$$2^n = \frac{R_o}{R}$$

$$2^n = \frac{137}{10} = 13.7$$

Using 2^n table, $n = 3.8$.

$$n = \frac{X}{X_{\frac{1}{2}}}$$

$$3.8 = \frac{X}{0.46}$$

$$X = 1.75 \text{ cm}$$

The lead shield must be 1.75 cm on a side.

(7) The transport index for the package does not exceed 10 mrem/hr at 3 feet.

2. Example Problem No. 2.

a. As outlined in example problem No. 1, what information must go on the shipping papers and how many labels must be attached?

b. Solution.

(1) As required on the shipping papers, the words "No Label Required" must be present if it is an exempt shipment. Since this shipment is not exempt, this notation is omitted.

(2) The transport group or groups if normal form - Group III. It is encapsulated, so it could be special form Group VII.

(3) Name of the radionuclide and a description of its physical or chemical form if the material is in normal form:

^{121}Te - encapsulated pellets.

(4) Activity of the radioactive material:

1 Ci of ^{121}Te.

(5) Transport Index - 10.

(6) Type of label applied:

Yellow III Label and DA Label 15.

(7) For fissile radioactive material, the fissile class of the package and the weight in grams or kilograms of the fissile isotope. NA

(8) For export shipment, a copy of any special permit issued by DOT for the package. NA

(9) Two labels must be attached - on opposite sides of the package.

3. Example Problem No. 3.

a. You, as RSO, are again asked to package a shipment of radioactive materials. This time the radionuclide is Cobalt-57 (^{57}Co). You are to ship 2 mCi of this material in a liquid solution and you wish to stay within the White I Label conditions. What type of container is required and what minimum size container would be procured? Should other material be added around the source?

b. Solution.

(1) Checking ^{57}Co, you find it is a group IV transport group material.

(2) For Type A packages - 20 curies can be shipped.

(3) Exempt materials 1 mCi - not exempt since 2 mCi are present.

(4) It is not a large quantity material.

(5) White I Label requirements - dose rate not exceeding 0.5 mrem/hr at external surface of the package.

(6) Calculations.

Go to decay scheme page 388, Pam 25 - n = 99.8% and E = 0.13632.

S = 0.56 nCE

S = 0.56 x 2 x 0.998 x 0.13632

S = 1.524×10^{-1} rhm

$$R = \frac{S}{d^2}$$

$R = 0.5$ mr/hr

$S = 1.524 \times 10^{-1}$ mrhm

$d = ?$

$$0.5 \text{ mr/hr} = \frac{1.524 \times 10^{-1} \text{ mrhm}}{d^2}$$

$$d^2 = \frac{0.1524}{0.5}$$

$d^2 = 0.305$

$d = \sqrt{0.305}$

$d = 0.552$ meter

The package must be 0.552 meter on one side so the total diameter must be twice this amount.

$0.552 \times 2 = 1.104$ meters on a side.

A square package 1.104 meters on a side if no shielding is used in the package.

(7) The liquid radioactive material must be packaged in leak resistant and corrosion resistant inner containers. Enough absorbent material must be provided to absorb at least twice the volume of radioactive liquid.

Transport group (see § 173.389(b))	Type A quantity (in curies)	Type B quantity (in curies)
I	0.001	20
II	0.05	20
III	3	200
IV	20	200
V	20	5,000
VI and VII	1,000	50,000
Special form	20	5,000

§ 173.390 **Transport groups of radionuclides.**

(a) List of radionuclides:

Element[1]	Radionuclide[3]	I	II	III	IV	V	VI	VII
		Transport group						
Actinium (89)	Ac-227	X						
	Ac-228	X						
Americium (95)	Am-241	X						
	Am-243	X						
Antimony (51)	Sb-122				X			
	Sb-124			X				
	Sb-125			X				
Argon (18)	Ar-37						X	
	Ar-41		X					
	Ar-41 (uncompressed)[2]					X		
Arsenic (33)	As-73				X			
	As-74				X			
	As-76				X			
	As-77				X			
Astatine (85)	At-211			X				
Barium (56)	Ba-131				X			
	Ba-133		X					
	Ba-140			X				
Berkelium (97)	Bk-249	X						
Beryllium (4)	Be-7				X			
Bismuth (83)	Bi-206				X			
	Bi-207			X				
	Bi-210		X					
	Bi-212			X				
Bromine (35)	Br-82				X			
Cadmium (48)	Cd-109				X			
	Cd-115m			X				
	Cd-115				X			
Calcium (20)	Ca-45				X			
	Ca-47				X			
Californium (98)	Cf-249	X						
	Cf-250	X						
	Cf-252	X						
Carbon (6)	C-14				X			
Cerium (58)	Ce-141				X			
	Ce-143				X			
	Ce-144			X				
Cesium (55)	Cs-131				X			
	Cs-134m			X				
	Cs-134			X				
	Cs-135				X			
	Cs-136				X			
	Cs-137			X				
Chlorine (17)	Cl-36			X				
	Cl-38				X			
Chromium (24)	Cr-51				X			
Cobalt (27)	Co-56			X				
	Co-57				X			
	Co-58m				X			
	Co-58				X			
	Co-60			X				
Copper (29)	Cu-64				X			
Curium (96)	Cm-242	X						
	Cm-243	X						
	Cm-244	X						
	Cm-245	X						
	Cm-246	X						
Dysprosium (66)	Dy-154			X				
	Dy-165				X			
	Dy-166				X			
Erbium (68)	Er-169				X			
	Er-171				X			
Europium (63)	Eu-150			X				
	Eu-152m				X			
	Eu-152			X				
	Eu-154		X					
	Eu-155				X			
Fluorine (9)	F-18				X			
Gadolinium (64)	Gd-153				X			
	Gd-159				X			
Gallium (31)	Ga-67			X				
	Ga-72				X			
Germanium (32)	Ge-71				X			
Gold (79)	Au-193			X				
	Au-194			X				
	Au-195			X				
	Au-196				X			
	Au-198				X			
	Au-199				X			
Hafnium (72)	Hf-181				X			
Holmium (67)	Ho-166				X			
Hydrogen (1)	H-3 (see tritium)							
Indium (49)	In-113m				X			
	In-114m			X				
	In-115m				X			
	In-115				X			
Iodine (53)	I-124			X				
	I-125			X				
	I-126			X				
	I-129			X				
	I-131			X				
	I-132				X			
	I-133			X				
	I-134				X			
	I-135				X			
Iridium (77)	Ir-190				X			
	Ir-192			X				
	Ir-194				X			
Iron (26)	Fe-55				X			
	Fe-59				X			
Krypton (36)	Kr-85m			X				
	Kr-85m (uncompressed)[2]					X		
	Kr-85			X				
	Kr-85 (uncompressed)[2]						X	
	Kr-87		X					
	Kr-87 (uncompressed)[2]					X		

See footnotes at end of table.

Element[1]	Radionuclide[3]	I	II	III	IV	V	VI	VII
		Transport group						
Yttrium (39)	Y-88			X				
	Y-90				X			
	Y-91m			X				
	Y-91			X				
	Y-92				X			
	Y-93				X			
Zinc (30)	Zn-65				X			
	Zn-69m				X			
	Zn-69				X			
Zirconium (40)	Zr-93				X			
	Zr-95			X				
	Zr-97				X			

[1] Atomic number shown in parentheses.
[2] Uncompressed means at a pressure not exceeding 14.7 p.s.i. (absolute).
[3] Atomic weight shown after the radionuclide symbol.
[4] Fissile radioactive material.

Element¹	Radionuclide	I	II	III	IV	V	VI	VII
Lanthanum (57)	La-140				X			
Lead (82)	Pb-203				X			
	Pb-210		X					
	Pb-212		X					
Lutecium (71)	Lu-172			X				
	Lu 177				X			
Magnesium (12)	Mg-28			X				
Manganese (25)	Mn-52				X			
	Mn-54				X			
	Mn-56				X			
Mercury (80)	Hg-197m				X			
	Hg-197				X			
	Hg-203				X			
Mixed Fission Products	MF-P		X					
Molybdenum (42)	Mo-99				X			
Neodymium (60)	Nd-147				X			
	Nd-149				X			
Neptunium (93)	Np-237	X						
	Np-239	X						
Nickel (28)	Ni-56			X				
	Ni-59				X			
	Ni-63				X			
	Ni-65				X			
Niobium (41)	Nb-93m				X			
	Nb-95				X			
	Nb-97				X			
Osmium (76)	OS-185				X			
	OS-191m				X			
	OS-191				X			
	OS-193				X			
Palladium (46)	Pd-103				X			
	Pd-109				X			
Phosphorus (15)	P-32				X			
Platinum (78)	Pt-191				X			
	Pt-193				X			
	Pt-193m				X			
	Pt-197m				X			
	Pt-197				X			
Plutonium (94)	Pu-238⁴	X						
	Pu-239⁴	X						
	Pu-240	X						
	Pu-241⁴	X						
	Pu-242	X						
Polonium (84)	Po-210	X						
Potassium (19)	K-42				X			
	K-43			X				
Praseodymium (59)	Pr-142				X			
	Pr-143				X			
Promethium (61)	Pm-147				X			
	Pm-149				X			
Protactinium (91)	Pa-230	X						
	Pa-231	X						
	Pa-233		X					
Radium (88)	Ra-223		X					
	Ra-224		X					
	Ra-226	X						
	Ra-228	X						
Radon (86)	Rn-220				X			
	Rn-222		X					
Rhenium (75)	Re-183				X			
	Re-186				X			
	Re-187				X			
	Re-188				X			
	Re Natural				X			
Rhodium (45)	Rh-103m				X			
	Rh-105				X			
Rubidium (37)	Rb-86				X			
	Rb-87				X			
	Rb Natural				X			
Ruthenium (44)	Ru-97				X			
	Ru-103				X			
	Ru-105				X			
	Ru-106			X				
Samarium (62)	Sm-145			X				
	Sm-147			X				
	Sm-151				X			
	Sm-153				X			

¹ See footnotes at end of table.

Element¹	Radionuclide²	I	II	III	IV	V	VI	VII
Scandium (21)	Sc-46			X				
	Sc-47				X			
	Sc-48				X			
Selenium (34)	Se-75				X			
Silicon (14)	Si-31				X			
Silver (47)	Ag-105				X			
	Ag-110m			X				
	Ag-111				X			
Sodium (11)	Na-22			X				
	Na-24				X			
Strontium (38)	Sr-85m				X			
	Sr-85				X			
	Sr-89			X				
	Sr-90		X					
	Sr-91			X				
	Sr-92				X			
Sulphur (16)	S-35				X			
Tantalum (73)	Ta-182			X				
Technetium (43)	Tc-96m				X			
	Tc-96				X			
	Tc-97m				X			
	Tc-97				X			
	Tc-99m				X			
	Tc-99				X			
Tellurium (52)	Te-125m				X			
	Te-127m				X			
	Te-127				X			
	Te-129m			X				
	Te-129				X			
	Te-131m			X				
	Te-132				X			
Terbium (65)	Tb-160			X				
Thallium (81)	Tl-200				X			
	Tl-201				X			
	Tl-202				X			
	Tl-204			X				
Thorium (90)	Th-227		X					
	Th-228	X						
	Th-230	X						
	Th-231	X						
	Th-232			X				
	Th-234		X					
	Th Natural			X				
Thulium (69)	Tm-168			X				
	Tm-170			X				
	Tm-171				X			
Tin (50)	Sn-113				X			
	Sn-117m			X				
	Sn-121			X				
	Sn-125				X			
Tritium (1)	H-3				X			
	H-3 (as a gas, as luminous paint, or adsorbed on solid material).							X
Tungsten (74)	W-181				X			
	W-185				X			
	W-187				X			
Uranium (92)	U-230		X					
	U-232	X						
	U-233⁴		X					
	U-234		X					
	U-235⁴			X				
	U-236		X					
	U-238			X				
	U Natural			X				
	U Enriched⁴			X				
	U Depleted			X				
Vanadium (23)	V-48				X			
	V-49			X				
Xenon (54)	Xe-125			X				
	Xe-131m			X				
	Xe-131m (uncompressed)³					X		
	Xe-133			X				
	Xe-133 (uncompressed)³						X	
	Xe-135		X					
	Xe-135 (uncompressed)³					X		
Ytterbium (70)	Yb-175				X			

SAMPLE

RADIOACTIVE MATERIALS MOVEMENT

☐ SHIPMENT ☐ RECEIPT

(AR 55-55)

SECTION I - DETAILS OF SHIPMENT

TO:	FROM:	VIA: (Mode of shipment, i.e. Railway Express)
SHIPMENT NO.	SIZE	WEIGHT
CLASSIFICATION	TYPE OF CONTAINER	PRINCIPAL RADIOACTIVE MATERIAL
ACTIVITY	DATE OF (Fill in as applicable) — SHIPMENT (Estimate)	RECEIPT
LOCATION	COLLECT	PREPAID

1. DOES/DID THIS SHIPMENT REQUIRE ICC SPECIFICATION PACKAGING AND LABELING? ☐ YES ☐ NO

   ICC NO. ____________ BUREAU OF EXPLOSIVES NO. ____________

2. IS/WAS THIS A COURIER SHIPMENT? ☐ YES ☐ NO

3. IS/WAS IT PACKAGED TO PREVENT LEAKAGE UNDER TRANSPORTATION CONDITIONS? ☐ YES ☐ NO

   IS/WAS THE SHIPMENT PROPERLY SECURED? ☐ YES ☐ NO

5. IS/WAS THE SHIPMENT PALLETIZED? ☐ YES ☐ NO

SIGNATURE OF CONSIGNOR/CONSIGNEE (As applicable)	DATE

SECTION II - HEALTH PHYSICS MONITORING RESULTS

MAXIMUM RADIATION LEVEL — AT SURFACE	AT 1 METER	AT 15 FEET
TYPE OF INSTRUMENT USED	INSTRUMENT SERIAL NO.	REMOVABLE SURFACE CONTAMINATION (d/m/100 cm2)

WIPE TEST MATERIAL USED	INSTRUMENT USED TO CHECK WIPE
INSTRUMENT SERIAL NO.	LOG NO.

REMARKS

DATE	TIME	RADIATION SURVEY APPROVED BY

SECTION III - RADIOLOGICAL SAFETY OFFICER'S STATEMENT OF MONITORING RESULTS

LOG NO.	BUREAU OF EXPLOSIVES SPECIAL PERMIT NO.	SAFE TO SHIP ☐ YES ☐ NO	SHIPMENT SAFE (Check upon receipt of shipment) ☐ YES ☐ NO

REMARKS

SIGNATURE OF RADIOLOGICAL OFFICER	DATE

SECTION IV - TRANSPORTATION OFFICER'S STATEMENT OF SHIPMENT

The above named articles are properly described and are packed and marked and are in proper condition for transportation according to the regulations prescribed by the appropriate regulatory agencies.

SIGNATURE OF TRANSPORTATION OFFICER	DATE

DA FORM 1 JUN 64 2791

V. Problems.

1. You, as Radiological Safety Officer, have been asked to ship for disposal 5 μCi of ^{117m}Sn powder contained in a screw top metal can. In inspection of the packages available, you find you have a Type A package which measures 0.5 meter to a side. The source is to be placed in the center of this package. Is this package sufficient? Examine the quantity, shielding and label requirements and make the most economical recommendation for transport of this material.

2. From the information in problem 1, what items are necessary on the shipping papers?

3. A 1.5 mCi sample of $^{96}_{43}Tc$ is to be shipped. You have both Type A and B packages measuring 1 meter to a side.

a. What transport group does this isotope fall under and which type of package will you use more economically?

b. Is this an exempt quantity? If not, what would be the best way to ship this material using the least amount of shielding possible? Consignee is awaiting shipment for immediate use.

4. Given the following isotopes in normal form:

4 curies	^{65}Ni
6 curies	^{64}Cu
0.4 curie	^{137}Cs
1 curie	^{60}Co

Can all of these isotopes be sent in one type A package(do not calculate shielding)?

5. a. You are RSO and have been asked to choose a container to ship 200 curies of Tellurium-125 metastable (^{125m}Te). What transport group and what type of package must be used?

b. You have decided to use lead as the inner container. How big would the container have to be if the overall package is to be 1 cubic meter? (Assume inner package is to be placed in the center of the outer package.) It is to be shipped Yellow III Label. Does it fall within the large quantity category?

6. You, as RSO, are again called upon to package a shipment of radioactive material. This time the substance is 10 mCi of Cobalt-57 (^{57}Co).

a. In what transport group does it fall and what type of package is required?

b. How big would the container have to be if you wished to ship radioactive Yellow II Label, with no shielding, and you meet all other requirements, i.e., leakproof, absorbent material, etc.?

VI. Solutions.

1. a. In checking ^{117m}Sn, you find it falls with the transport group III category. Three curies of group III can be transported in a type A package, so the package available is sufficient.

   b. In examination of the quantity of material (5 µCi) you find it falls in the small quantity category (1 mCi for group III) and it can be shipped exempt from labeling provided.

      (1) Strong package and no leakage under normal transport conditions.

      (2) No significant external surface contamination.

      (3) Outer surface of the inner package is marked "Radioactive."

      (4) Dose rate at the external surface of the package does not exceed 0.5 mrem/hr.

      Calculate the source strength.

      $S = 0.56\ nCE \qquad 5\ \mu Ci = 5 \times 10^{-3}\ nCi$

      $S = 0.56 \times 0.87 \times 5 \times 10^{-3} \times 0.158$

      $S = 0.385 \times 10^{-3}$ mrhm

      The box is 0.5 meter per side. So, with the source in the center, it will be 0.25 meter from the nearest side.

      $d = 0.25$ meter.

      Calculate the dose rate at the surface of the container.

      $$R = \frac{S}{d^2}$$

      $$R = \frac{3.85 \times 10^{-4}}{(0.25)^2} \quad \frac{3.85 \times 10^{-4}}{6.25 \times 10^{-2}}$$

      $R = 6.16 \times 10^{-3}$ mr/hr,

      or 0.00616 mr/hr at the surface. Since it is γ, it is the same as 0.00616 mrem/hr. The package falls in exempt group and can be shipped without label.

2. a. Since it is an exempt item, the words "No Label Required."

b. Transport Group III.

c. Name of radionuclide - ^{117m}Sn.

Description - powder form contained in metal screw cap can.

d. Activity of radionuclide - 5 ~~μCi.~~

e. Transport Index - NA since it is exempt.

f. Fissile radionuclide - NA.

g. Export shipment - NA.

3. a. Checking $^{96}_{43}Tc$, you find it is group IV. Group IV allows a 20 curie shipment in a type A package so the type A package will be used.

b. Exempt quantity for group III is 1 mCi, so this package is not exempt. Calculate the dose rate at the surface and at 3 feet from the surface.

Calculate the source strength.

$$S = 0.56\ C\ \Sigma n\ E$$

$$= (0.56)(1.5\ \text{mCi})\left[(0.05)(0.32) + (1)(0.778) + (0.84)(0.81) + (1)(0.851) + (0.16)(1.12)\right]$$

$$= (0.56)(1.5\ \text{mCi})(0.016 + 0.778 + 0.6804 + 0.851 + 0.1792)$$

$$= (0.56)(1.5\ \text{mCi})(2.5046)$$

$$= 2.105\ \text{mrhm}$$

Since the package is 1 meter to the side, if the source is located in the center, it will be 0.5 meter from the nearest side. d = 0.5 meter. Calculate R.

$$R = \frac{S}{d^2} \qquad\qquad R = \frac{S}{d^2}$$

$$R = \frac{2.105}{(0.5)^2} \qquad\qquad R = \frac{2.105}{(1.5)^2}$$

$$R = \frac{2.105}{0.25} \qquad\qquad R = \frac{2.105}{2.25}$$

R = 8.42 mr/hr at contact. R = 0.935 mr/hr at 1 meter from the surface.

Since γ 8.42 mrem/hr at contact 0.935 mrem/hr at 3 feet

Since it exceeds the White I label and the dose rate at 3 feet exceeds the Yellow II label, ship it Yellow III with no additional shielding required.

4. $\frac{Ca}{MPCa} + \frac{Cb}{MPCb} + \frac{Cc}{MPCc} + \frac{Cd}{MPCd} \leq 1$

^{65}Ni - Group IV - allowed 20 curies in Type A package.

^{64}Cu - Group IV

^{137}Cs - Group III - allowed 3 curies in Type A package.

^{60}Co - Group III

$$\frac{4}{20} + \frac{6}{20} + \frac{0.4}{3} + \frac{1}{3}$$

$$0.2 + 0.3 + 0.133 + 0.33$$

$$0.96 < 1$$

Therefore all could be handled provided enough shielding could be incorporated to get the dose rate level within limits.

5. a. ^{125m}Te - Group IV. Type A, 20 curies; Type B, 200 curies. It exceeds Type A limits but does not exceed Type B limits. So Type B package will be used.

b. Large quantities for Group IV - 200 curies - we have only 200 curies, so it does not fall into this category.

200 curies of ^{125m}Te

$S = 0.56\ nCE = 0.56 \times 0.07 \times 200 \times 0.035$

Therefore, $S = 0.274$ rhm $= 274$ mrhm

To find R:

$R = \frac{S}{d^2} = \frac{274 \text{ mrhm}}{(0.5)^2} = \frac{274}{0.25} =$ 1,096 mrad/hr at 0.5 meter which is the surface.

Yellow III label requirements are that the surface dose rate does not exceed 200 mrad/hr and the dose rate at 3 feet (1 meter) from the surface does not exceed 10 mrad/hr.

Calculate how much lead is needed to reduce the dose rate to the required level.

<u>Surface</u>

$R_o = 1{,}096$ mrad/hr

$R = 200$ mrad/hr

μ/ρ for a 0.035 gamma $= 21.85\ cm^2/g$ Use largest gamma for shielding - 0.035 Mev

$\mu = \mu/\rho\ (\rho) = 21.85 \times 11.35 = 248\ cm^{-1}$

$X_{\frac{1}{2}} = \frac{0.693}{\mu} \quad \frac{0.693}{248\ cm^{-1}} = 0.000279\ cm = 2.79 \times 10^{-4}\ cm$

$\frac{R_o}{R} = \frac{1{,}096}{200} = 5.48 = 2^n$

Therefore $n = 2.5$ (from 2^n table)

$X = nX_{\frac{1}{2}}$

$X = 2.5 \times 2.79 \times 10^{-4} = 6.97 \times 10^{-4}$ cm or 0.000697 cm

Therefore, 0.000697 cm of lead required to meet the surface requirements.

Three feet (1 meter)

$$R_o = \frac{S}{d^2} = \frac{274}{(1.5)^2} = \frac{274}{2.25} = 121.8 \text{ mrad/hr}$$

$R = 10$ mrad/hr

$X_{\frac{1}{2}} = 2.79 \times 10^{-4}$

$X = ?$

$$\frac{R_o}{R} = \frac{121.8}{10} = 12.18 \doteq 2^n$$

Therefore $n = 3.7$ (from 2^n table)

$X = nX_{\frac{1}{2}}$

Therefore $X = 3.7 \times 2.79 \times 10^{-4} = 0.001032$ cm

0.001032 cm of lead required to meet the requirements at 3 feet or one meter. Since this is the greater amount, it will be used for the shield. 0.001032 x 2 radius = 0.002064 total cm of lead. However, this is not practical. You could use air to shield this source. That would require approximately 0.07 cm of air and you certainly have that much around the source.

6. a. It is not exempt. It is a group IV material with 20 curies allowed in a type A package. We have only 10 mCi, so type A packaging is to be used.

b. Yellow II requirement - 10 mrem/hr at surface and 0.5 mrem/hr at 3 feet (1 meter) from surface.

Calculate the source strength.

$S = 0.56\ nCE \doteq 0.56 \times 0.998 \times 10 \times 0.13632$ (page 388, Pam 25)

$S = 7.62 \times 10^{-1}$ mrhm

Dose Rate

$$R = \frac{S}{d^2}$$

$R = 10$ mrad/hr

$S = 7.62 \times 10^{-1}$ mrhm

Therefore, $d = \sqrt{\frac{0.762}{10}} = \sqrt{0.0762}$

$d = 0.276$ m

This is using dose rate at the surface.

$R = \frac{S}{d^2}$

R = 0.5 mrad/hr at 1 meter from surface

$S = 7.62 \times 10^{-1}$

$d = \sqrt{\frac{0.762}{0.5}} = \sqrt{1.524}$ meters

$d = 1.235$

1.235 m - 1 m = 0.235 m from center of box to surface of box.

$\therefore$ 0.276 x 2 = 0.552 meter to a side for the minimum size of the box.

POSTAL REQUIREMENTS FOR RADIOACTIVE MATERIAL

I. Nonmailable Matter.

A. Any package of radioactive material marked with White I, Yellow II, or Yellow III labels or which contains quantities of radioactive material in excess of those authorized in paragraph IIA is nonmailable.

B. If a nonmailable package of radioactive material is discovered intact in the postal system, the postmaster shall immediately

1. Place the parcel at least 15 feet from other mail or personnel. Under no circumstances shall the package be dispatched.

2. Notify the postal inspector in charge promptly, requesting instructions as to the disposition of the package.

3. If a package of nonmailable radioactive material is broken or leaking, the area around the damaged package must be isolated to prevent contact of persons with any loose radioactive material. Any conveyor, belt, chute, or other equipment or conveyance, including mail bags, in which the radioactive material has leaked, or may have leaked, should also be isolated. The isolated area must be roped off or guarded, whenever practical. A temporary sign indicating the presence of radioactive materials, with a warning to keep out, should be placed at the edge of the roped area. The postmaster, in cooperation with a postal inspector, if one is available, shall immediately request the assistance of qualified persons to check radiation hazards and to supervise the salvage and decontamination. This assistance may be received from the sender, if he is nearby, or from one of the following:

a. Nearest office of the U.S. Nuclear Regulatory Commission. The Nuclear Regulatory Commission offices are located as follows:

Operations Office	Mail Address	Telephone Number
Albuquerque	P.O. Box 5400, Albuquerque, New Mexico 87115	(505)264-4667
Chicago	9800 South Cass Avenue, Argonne, Illinois 60439	(312)739-7711 ext 2111 or 4451
Richland	P.O. Box 550, Richland, Washington 99352	(509)942-1111 ext 6-5441

Operations Office	Mail Address	Telephone Number
Idaho	P.O. Box 2108, Idaho Falls, Idaho 83401	(208)526-0111 ext 1515
New York	376 Hudson Street New York, New York 10014	(212)989-1000
Oak Ridge	P.O. Box E, Oak Ridge, Tennessee 37830	(615)483-8611 ext 34510
San Francisco	2111 Bancroft Way, Berkeley, California 94704	(415)841-5121 ext 664 or 841-9244
Savannah River	P.O. Box A, Aiken, South Carolina 29801	N. Augusts, S. C. (803)824-6331 ext 3333

b. Local health, fire, or police department.

c. Local civil defense authorities.

d. Nearby military installation.

e. Nearby scientific laboratory.

II. Matter Mailable Under Special Rules.

Authorized mailable radioactive materials include only those which are classified as "small quantities" of radioactive materials or "radioactive devices," as prescribed in 49 Code of Federal Regulations 173.391. These authorized materials, the maximum quantities mailable, and the conditions under which they may be mailed are described below:

A. Small Quantities (49 CFR 173.391(a)).

Transport Group (173.389(h)) (173.390)	Maximum Quantity per Package
I	0.01 milicurie
II	0.1 millicurie
III, IV, V, or VI	1.0 millicurie
VIII	25.0 curies
Special form radioactive materials (173.389(g))	1.0 millicurie
Tritium oxide in aqueous solution	0.5 millicurie/milliter (3 curies/package limit)
Fissile radioactive materials (173.389(a))	15 grams*

*The total radioactivity may not exceed either the applicable activity limit for the appropriate transport group or the special form radioactive material limit.

B. How to Wrap and Mail.

1. The above materials must be securely contained in strong, tight packages to prevent leakage of the contents during normal postal handling. Liquid radioactive materials must additionally be packaged within a leak resistant and corrosion resistant inner container, surrounded by sufficient absorbent material to absorb at least twice the volume of the liquid radioactive contents.

2. The radiation dose rate at any point on the external surface of the package must not exceed 0.5 millirem per hour.

3. There must be no significant radioactive material on the exterior of the package (49 CFR 173.397).

4. The outside of the inner container must bear the marking "radioactive Material - No Label Required."

C. Radioactive devices (49 CFR 173.391(b)) - Manufactured articles such as instruments, clocks, electronic tubes, or apparatus, or other similar devices, having radioactive materials (other than liquids) in a nondispersible form, as a component part, are mailable providing that the following conditions are met:

1. The radioactive materials must be securely contained within the devices, or securely packaged in strong tight packages, such that there will be no leakage of radioactive materials under conditions normally encountered in postal handling.

2. The radiation dose rate at 4 inches from any unpackaged package device must not exceed 10 millirem per hour.

3. The radiation dose rate at any point on the external surface of the outside container does not exceed 0.5 millirem per hour.

4. There must be no significant radioactive material on the exterior of the package (49 CFR 173.397).

5. The total radioactivity content of a single package containing radioactive devices must not exceed the quantities shown in the following table:

Transport Group	Quantity in Curies	
	Per Device	Per Package
I	0.0001	0.001
II	0.001	0.05

Transport Group	Quantity in Curies Per Device	Per Package
III	0.01	3.0
IV	0.05	3.0
V or VI	1.0	1.0
VII	25.0	200.0
Special form radioactive materials	0.05	20.0
Fissile radioactive materials	15 grams*	15 grams*

*The total radioactivity may not exceed either the applicable activity limit for the appropriate transport group or the special form radioactive material limit.

RADIOACTIVE MATERIALS MOVEMENT

☐ SHIPMENT ☐ RECEIPT

For use of this form, see AR 55-55, the proponent agency is Office of the Deputy Chief of Staff for Logistics

(See instructions on reverse.)

DETAILS OF SHIPMENT

1 TO: *(Include ZIP Code)*	2 FROM: *(Include ZIP Code)*

3 SHIPMENT NUMBER	4 SECURITY CLASSIFICATION	5. MODE OF SHIPMENT *(i.e., Railway Express)*

6 COMMODITY DESCRIPTION			7 RADIOACTIVITY		
				b LEVEL	
CONTAINERS a	NUMBER OF ITEMS b	NOMENCLATURE c	QUANTITY, ISOTOPE AND FORM a	AT SURFACE	AT ONE METER

SHIPMENT

THE ABOVE DESCRIBED ARTICLES ARE PROPERLY CLASSIFIED, PACKAGED, MARKED, AND LABELED. THE ARTICLES ARE IN PROPER CONDITION FOR TRANSPORTATION AND THE SPREADABLE ACTIVITY AND DOSE RATES ARE WITHIN THE SPECIFIED LIMITS, AS PRESCRIBED BY APPLICABLE REGULATIONS OF THE DEPARTMENT OF TRANSPORTATION AND DEPARTMENT OF THE ARMY

8 REMARKS

9 SPECIAL PRECAUTIONS

10. SIGNATURE OF RADIATION PROTECTION OFFICER *(Shipping Organization)*		DATE
11 SIGNATURE OF TRANSPORTATION OFFICER *(Shipping Organization)*	GRADE AND TITLE	DATE
12 ORGANIZATION		

DA FORM 2791-R, 1 Oct 70

REPLACES DA FORM 2791, 1 JUN 64, WHICH IS OBSOLETE

(Paper size, 8" x 10½", image size, 7-4/10" x 10")

Front

Figure 8-7. DA Form 2791-R.

RECEIPT

THE ARTICLES DESCRIBED ON REVERSE WERE RECEIVED IN PROPER TRANSPORTATION CONDITION. THE SPREADABLE ACTIVITY AND DOSE RATES ARE WITHIN THE SPECIFIED LIMITS AS PRESCRIBED BY APPLICABLE REGULATION OF THE DEPARTMENT OF TRANSPORTATION AND THE DEPARTMENT OF THE ARMY EXCEPT AS NOTED BELOW.

13. REMARKS		
14. SIGNATURE OF RADIATION PROTECTION OFFICER *(Receiving Organization)*		DATE
15. SIGNATURE OF CONSIGNEE	GRADE AND TITLE	DATE
16. ORGANIZATION		

INSTRUCTIONS

GENERAL

Forms will be used to identify radioactive shipments originated by Army elements for protection of shipping, transporting, and receiving personnel and to assure compliance with DA and other regulations. Receiving organizations will use the form to record receipt of radioactive shipments from Army and non-Army elements and to indicate any necessary radiation protection action. Certification by the radiation protection officer indicates that all necessary radiation surveys and smear tests were made with appropriate radiation/contamination measuring devices. See also paragraph 3-5, AR 55-55. Shipping organizations will complete three copies, retain one for record purposes, and deliver one to the carrier who will deliver one copy to the receiving organization. When forms are originated by receiving organizations, sufficient copies will be prepared for record purposes and use in follow-up action as necessary.

EXPLANATION OF FORM

1. Items 1, 2, 3, 4, 5. Self-explanatory.

2. Item 6a. Indicate number and kind of packages and package markings, if marked.

3. Item 6b. Indicate number of items contained in package(s) shown in column 6a. Each type of item should be listed separately.

4. Item 6c. Enter sufficient information to identify the item(s). Include Federal Stock Number, if any.

5. Item 7a. Show total number of curies, millicuries, or microcuries contained in package(s) in Column 6a. and, if available, the number of curies, millicuries or microcuries contained in each item. Indicate chemical element and mass number of radioisotopes and whether liquid, solid, or gaseous, and sealed or unsealed.

6. Item 7b. Indicate radiation levels in mR/hr.

7. Item 8. Self-explanatory.

8. Item 9. List special precaution necessary in handling, transporting and storing. Where shipments are at variance with or are exempted from portions of the regulations (i.e., labeling, packaging, container specification), include a statement to so indicate and list specific authority for the variance or exemption.

9. Items 10, 11, 12. Self-explanatory.

10. Item 13. Record exceptions to receipt statement and follow-up actions taken. If none, so indicate.

11. Items 14, 15, 16. Self-explanatory.

Back

Figure 8-7—Continued.

DF410

DISPOSAL OF RADIOACTIVE MATERIAL

DF410, DISPOSAL OF RADIOACTIVE MATERIAL

I. References: Handouts - Section III; TM 3-260; AR 755-15; CFR Title 10, Part 20.

II. Lesson Objectives and Notes.

A. Federal Waste Disposal Regulations.

B. DA Waste Disposal Program.

C. Present and Future Methods of Waste Disposal.

Notes:

III. Handouts:

A. Examples.

B. Vu-Graphs used in lesson presentation.

DEPARTMENT OF THE ARMY
U. S. ARMY CHEMICAL CENTER AND SCHOOL
Fort McClellan, Alabama 36201

SUBJECT: Request for Disposition Instructions

THRU: Commanding Officer
USA School/Training Center
Fort McClellan, Alabama 36201

CG, Third U. S. Army
ATTN: AJAGL-D-S-S (Radioactive Material Control Point)
Fort McPherson, Georgia 30330

CG, USCONARC
ATTN: ATLOG-S/GS
Fort Monroe, Virginia 23351

TO: Commanding Officer
US Army Edgewood Arsenal
ATTN: SMUEA-ISCP (Radioactive Material Disposal Facility)
Edgewood Arsenal, Maryland 21010

Under the provisions of para 15, AR 755-15, request disposition instructions for the following radioactive waste material.

a. Nomenclature: Solid waste material, no FSN.

b. Physical description of items:

(1) Solid

(2) Quantity: Not applicable

(3) Number of individual items per package and type of packages: See para (6) below.

(4) Number of shipping containers: Twenty-seven (27)

(5) Exterior dimensions and weight of packaged shipping container: Thirteen (13) fifty-five gallon drums weighing approximately 1,000 pounds with a cubage of 10.9 cubic feet each; fourteen (14) twenty-three gallon drums weighing approximately 50 pounds each with a cubage of 3.2 cubic feet each.

(6) Shielding material and thickness: The fifty-five gallon drums contain a twenty-three gallon drum centered with a dense concrete poured completely surrounding it. (At least 8" on top and bottom and 4" on sides.) The twenty-three gallon shipping containers contain no shielding material.

(7) Department of Transportation permit or waiver number: Not applicable.

SUBJECT: Request for Disposition Instructions

d. Quantity and radiation measurements.

(1) Millicuries of activity of each radioisotope: Unknown.

(2) Maximum radiation dose rates (mrad/hr) at the surface and at one meter from the surface of the radioactive item: This waste material consists of glassware, filter paper, paper towelling, cotton swipes, smear paper, sawdust, an inert 155mm projectile, an inert 105mm projectile, and pavement surfacing determined to be contaminated to an extent that resurfacing was necessary; therefore, no measurements of the items can be determined.

(3) Maximum radiation dose rates (mrad/hr) at the surface and at one meter from the surface of the packages: See inclosure 1.

FOR THE COMMANDANT:

1 Incl
as

RADIOACTIVE WASTE MATERIAL

Container No.	Surface Reading mrad/hr	Reading at One Meter mrad/hr
23 Gallon Drums		
1	2	0.3
2	8	0.4
3	10	1.0
4	30	0.6
5	160	2.0
6	190	4.5
7	170	4.3
8	140	3.5
9	190	4.4
10	30	1.9
11	110	3.3
12	180	4.2
13	100	3.1
14	90	2.8
55 Gallon Drums		
15	6	0.7
16	90	3.5
17	5	0.8
18	106	3.5
19	120	2.8
20	70	3.0
21	46	2.9
22	150	3.6
23	25	1.9
24	180	5.0
25	190	3.9
26	120	2.9
27	90	2.2

SMUEA-ISCP (30 Dec 68) 1st Ind
SUBJECT: Request for Disposition Instructions
U. S. ARMY EDGEWOOD ARSENAL, Edgewood Arsenal, Maryland 21010
5 February 1969

Commanding General, U. S. Continental Army Command, ATTN: ATLOG-S/GS,
Fort Monroe, Virginia 23351

1. The radioactive material described in basic letter may be shipped to Transportation Officer, Army Chemical Center, Maryland for: Radioactive Material Disposal Section, U. S. Army Eastern Chemical Depot, with TWO COPIES of shipping document.

2. The material must be securely packaged, sealed airtight in a strong outside container and shipped in accordance with Title 49, Parts 171 to 179, Code of Federal Regulations, Transportation, in regard to external dose rates, removable contamination on the package surface, container structure, marking and labeling. Local Transportation Officer has appropriate shipping criteria.

3. The certificate referenced in Title 49, CFR, paragraph 173.430, should be placed on each copy of shipping documents and signed.

4. Shipment by Parcel Post or any other US Mail is PROHIBITED. Packages shipped should be marked to indicate consignee, consignor, and content nomenclature. Shipment should be completed by 28 February 1969.

FOR THE COMMANDER:

1 Incl
nc

ROBERT L. DEAN
Chief, Toxic and Radiological Branch

* * * * * * * *

SHIPPING CONTAINER TALLY → 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

REQUISITION AND INVOICE/SHIPPING DOCUMENT

1 FROM	Property Officer, USA Cml Cen & Sch Fort McClellan, Alabama 36201
2 TO	Commanding Officer USA Edgewood Arsenal Edgewood Arsenal, Maryland
3 SHIP TO - MARK FOR	ATTN: SMUEA-ISCP
SHEET NO	1
NO OF SHEETS	1
5 REQUISITION DATE	
6 REQUISITION NUMBER	32[illegible]3-0050
7 DATE MATERIEL REQUIRED	
8 PRIORITY	
9 AUTHORITY OR PURPOSE	AR 755-15
10 SIGNATURE	
11a VOUCHER NUMBER AND DATE	
b.	
12 DATE SHIPPED	19 Feb 69
13 MODE OF SHIPMENT	HALL MOTOR
14 BILL OF LADING NUMBER	C-0285781
15 AIR MOVEMENT DESIGNATOR OR PORT REFERENCE NO	

4 APPROPRIATION SYMBOL AND SUBHEAD	OBJECT CLASS	EXPENDITURE ACCOUNT (From)	(To)	CHARGEABLE ACTIVITY	BUREAU CONTROL ACTIVITY NO	BUREAU CONTROL NO.	AMOUNT

ITEM NO (a)	FEDERAL STOCK NUMBER DESCRIPTION AND CODING OF MATERIEL AND/OR SERVICES (b)	UNIT OF ISSUE (c)	QUANTITY REQUESTED (d)	SUPPLY ACTION (e)	TYPE CONTAINER (f)	CONTAINER NOS (g)	UNIT PRICE (h)	TOTAL COST (i)
1.	Radioactive waste (55 gallon drums)	ea		7	drum	1/7		

This is to certify that the above named articles are properly described, and are packed and marked, and are in proper condition for transportation according to the regulations prescribed by the Department of Transportation.

Please sign one copy of Shipping Document and return to: Property Officer
USA Chemical Center and School
Fort McClellan, Alabama 36201

16 TRANSPORTATION VIA MATS OR MSTS CHARGEABLE TO

17 SPECIAL HANDLING

18 RECAPITULATION OF SHIPMENT	TOTAL CONTAINERS	TYPE CONTAINER	DESCRIPTION	TOTAL WEIGHT	TOTAL CUBE
ISSUED BY	7	drum	Radioactive waste	5600	
CHECKED BY					
PACKED BY					
	7		← TOTAL →	5600	

19 RECEIPT	DATE	BY	
CONTAINERS RECEIVED EXCEPT AS NOTED			SHEET TOTAL
QUANTITIES RECEIVED EXCEPT AS NOTED			GRAND TOTAL
POSTED			20 RECEIVER'S VOUCHER NO.

DD FORM 1 MAR 59 1149 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

REPLACES EDITION OF 1 MAY 58 WHICH MAY BE USED.

B. Vu-Graph Material Used in Lesson.

Vu-Graphs

1. Accumulating Organization

Any Army activity, other than a radioactive material disposal facility, which generates or accumulates radioactive materials.

2. Local Storage

Storage of unwanted radioactive material on a temporary basis only at places other than the Army radioactive material disposal facility.

3. Army Radioactive Material Disposal Facility

A facility which receives radioactive material from accumulating organizations and which also stores, concentrates, packages, marks, labels, ships, and effects the ultimate disposal of radioactive material.

4. Radioactive Material

Any material or combination of materials that spontaneously emit ionizing radiation.

(1) Radioisotope - any isotope which is radioactive

(2) Source material

(3) Special nuclear material

5. SS Material

Collective term for both source and special nuclear material. SS material includes plutonium, thorium, Uranium-233, Uranium-235, and Uranium-239. In addition, whenever deterium, tritium, enriched lithium, or compounds of these materials are employed in special weapons applications, they are considered to be SS material and must be controlled and accounted for as such.

6. Disposal

The act of getting rid of unwanted radioactive material under proper authority. Disposal may be accomplished by, but is not limited to, transfer. donation, sale, or ultimate removal from the environment.

Vu-Graphs

7. Ultimate Disposal

The removal of radioactive material from man's immediate habitat. Ultimate disposal includes sea disposal, land burial, incineration, and disposal into the sewerage system or into local streams. It does not include action taken to return sources and special nuclear material to DASA or the US Nuclear Regulatory Commission (NRC) for reprocessing.

Sea Disposal - Burying radioactive materials at sea, in water more than 1,000 fathoms deep and not less than 10 miles from shore.

8. Radioactive Waste

Unwanted material contaminated with radioisotopes including SS material, special weapons radioactive waste, and radioactive waste associated with production, possession, and use of radioactive material. Radioactive waste will include property which while originally non-radioactive has become contaminated to such an extent that it is economically unsound to decontaminate or the contamination cannot be reduced to a safe level.

9. SS Nuclear Waste

Source and special nuclear residues which cannot be economically separated from those materials which they have contaminated.

Controlled Area - any area which is restricted for the purpose of protection of personnel from exposure to radiation and radioactive materials.

Uncontrolled Area - any area which is not a controlled area.

10. Responsibility of CG of AMC

a. Formulates policies, procedures and methods.

b. Establishment of Army radioactive material disposal facilities.

c. Conducting studies and investigations to provide up-to-date methods.

d. Designing containers for radioactive waste.

e. Providing technical assistance.

Vu-Graphs

10. (cont)

f. Providing technical advice for the establishment and operation of Army radioactive material disposal facilities.

g. Provide qualified technical escort personnel.

(Not a VG) Oversea Commanders

Major oversea commanders, with the exception of the CG, Southern Command, are responsible for the following:

(1) The establishment and operation of oversea radioactive material disposal facilities as required for the receipt, storage, marking, packaging, labeling, and shipment of radioactive material for ultimate disposal.

(2) Support of the radioactive material disposal facilities with personnel and equipment.

(3) The establishment of qualified escort of radioactive waste shipments within the oversea theater as may be required.

(Not a VG) Special Problems

Special radioactive waste disposal problems requiring logistical assistance will be directed to CG, U. S. Army Materiel Command, ATTN: AMCMA-DA. Problems involving licensing regulations, decontamination, and/or radiological safety will be routed to CG, U. S. Army Materiel Command, ATTN: AMCAD-S.

11. Segregation of Material

Combustible

Gas
Liquid
Solid

Noncombustible

Gas
Liquid
Solid

Vu-Graphs

12. Storage of Isotopes

Materials will be stored in covered containers. Each container having radioactive materials stored therein will display the following up-to-date information:

(1) Radiation symbol and words "Caution - Radioactive Materials."

(2) Radioisotope present.

(3) Level of activity; i.e., number of curies, millicuries or microcuries.

(4) Date on which the level of activity was measured.

(5) Maximum dose rate (mrad/hr) at the surface of the container.

(6) Maximum dose rate (mrad/hr) at 1 meter from the surface.

13. Area Posting

"Radiation area" for the purpose of disposal of unwanted radioactive materials means any area, accessible to personnel, in which there exists ionizing radiation, originating in whole or in part within licensed or unlicensed (or radioactive) material, at such levels that a major portion of the body could in any hour receive a dose in excess of 5 millirem. If this area exists outside a fenced-in area it will be delineated and proper signs placed.

14. High Radiation Area

A "High Radiation Area" is any area accessible to personnel in which there exists radiation at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem. If this area exists for more than 30 days, it will be equipped with control devices as required in Title 10, CFR 20.203.

15. Airborne Radioactivity Area

An "Airborne Radioactivity Area" is a room, enclosure, or area in which the airborne radioactive materials exist in concentrations in excess of 25 percent of the amounts specified in App B, Table I, Column I of Title 10, CFR 20.

Vu-Graphs

16. Marking of Radioactive Materials and Containers

Each room, area or enclosure containing radioactive materials will be conspicuously posted with "radioactive material" warning signs.

Storage or shipping containers containing radioactive materials will be conspicuously posted with the radioactive material tag. The information requested on the tag will be completed in indelible ink or pencil.

17. Sources of Waste Material, Liquid and Solid

Ore processing results in low-specific activity waste containing alpha emitting isotopes of uranium.

Decontamination wastes are usually characterized by large volume and small quantity of radioactivity, the result of flushing or rinsing to effect decontamination.

Cooling fluids from operating nuclear reactors become radioactive largely as the result of neutron bombardment of the coolant itself.

Laboratory waste will produce high levels of activity and will be small in volume. Decontamination of glassware, gloves, and equipment will produce large quantities of low level waste.

18. Types of Waste

High level waste is that having an activity level of a curie or a curie per gallon if liquid.

Intermediate level waste is that having an activity level of a millicurie or a millicurie per gallon if liquid.

Low level waste is that having an activity level of a microcurie or a microcurie per gallon if liquid.

19. Information in Disposal Request

1. Nomenclature and National Federal stock number and, when applicable, serial numbers will be shown.

2. Physical description of items to include:

   a. Solid and liquid.

   b. Quantity (number, weight and volume).

c. Number of individual items per package and type of package.

d. Number of shipping containers.

e. Exterior dimension and weight of packaged shipping container.

f. Shielding material and thickness, if applicable.

g. Department of Transportation (B of E) permit or waiver number, if applicable.

20. Other Information Needed

1. Chemical and radioisotopic description.

a. Hazardous chemicals present.

b. For liquids, the solvent present.

c. Radioisotopes present.

2. Quantity and radiation measurement to include:

a. Millicuries of activity of each radioisotope.

b. Maximum radiation dose rate (mrad/hr) at the surface and at 1 meter from the surface.

21. Labeling for Common Carrier Shipment.

1. Radiation symbol and "Caution Radioactive Material."

2. Consignee.

3. Maximum dose rate in mr/hr at surface of package.

4. Maximum dose rate in mr/hr at 1 meter from the package.

5. Radioisotope present.

6. Amount of radioactivity; i.e., number of curies, millicuries, or microcuries.

(Not a VG)

Requests for disposal instructions should be submitted through major CONUS Command Radioactive Material Control Point to:

Commanding Officer
USA Edgewood Arsenal
ATTN: SMUEA-ISCP
Edgewood Arsenal, Maryland 21010

Vu-Graphs

22. Ultimate Disposal

1. Burial of waste material.

2. Sea disposal.

3. Sanitary sewerage disposal.

4. Transfer to other licensees.

5. Underground storage.

6. Incineration.

23. Burial of Waste Materials

Regulated by paragraph 20.203, Part 20, Title 10, CFR.

(1) 1,000 x limits set in App C, Title 10, Part 20, CFR.

(2) 4 feet deep.

(3) 6 feet apart.

(4) 12 burials per year.

(5) No more than 1 curie can be buried.

(6) Should be marked and in an isolated area.

(Not a VG)

Sanitary Sewerage Disposal (regulated by para 20.303, Part 20, Title 10, CFR).

No licensee shall discharge licensed material into a sanitary sewerage system unless:

(1) It is readily soluble or dispersible in water.

(2) The quantity in 1 day, if diluted by the average daily quantity of sewerage released into the sewer by the licensee, will result in an average concentration equal to the limits specified in App B.

Table I, Column 2, or ten times the quantity of such material specified in App C of this part. The larger value is to be taken:

(1) In any one month, if diluted by the average monthly quantity of water released by the licensee, will not result in an average concentration exceeding the limits specified in App B, Table I, Column 2.

(2) The gross quantity of licensed and radioactive material released into the sewerage system by the licensee does not exceed 1 curie per year.

24. (Not a VG) App C, Title 10, Part 20, CFR.

Records.

a. Personnel.

b. Swipe Test.

c. Vault Readings.

d. Disposal Readings.

IV. Problems.

1. You have recently been assigned as the Radiological Safety Officer at an installation. One of your duties is disposal of radioactive materials. One of the using agencies at this installation has turned in 0.1 µCi of ^{111}Ag soluble. What avenues are open to you for disposal of this material?

2. Following the situation as outlined in problem 1, if the sanitary sewerage is to be used, what operations must be accomplished? (Work the solution out in detail.)

3. If in the above situation the isotope had been ^{125}Sn soluble and the quantity was 1 μCi, what action would be necessary to dispose of this material through the sanitary sewerage?

4. You, as disposal officer, are given a small amount of liquid solution containing ^{210}Pb. The reading you get on this sample after all corrections are made is 2,500 disintegrations per second. You wish to dispose of this isotope through the sanitary sewerage system. What action must be taken?

5. An unknown isotope gives reading of 30,000 disintegrations per minute after corrections have been made. What action must be accomplished to dispose of this material through the sanitary sewerage system?

6. You, as disposal officer, have been given the following amount of radioactive material in liquid solution: 50µCi of ^{14}C, 35µCi of ^{72}Ga, 4.2 µCi of ^{59}Fe, 5µCi of ^{185}W and 6 µCi of ^{131}I. Can this material be disposed of through the sanitary sewerage if the average monthly flow of water through the sanitary sewerage is 9×10^9 ml. You have no previous dump in the sanitary sewer.

V. Solutions.

1. a. Request disposal instructions through major CONUS Command Radioactive Material Control Point, from:

   Commanding Officer
   ATTN: SMUEA-ISCP
   APG-EA, Maryland 21005

   Ship the material according to instructions following the regulations established by the Department of Transportation.

   b. Dispose of the material through the sanitary sewerage.

   c. Store material and allow for decay since this isotope has a rather short half-life.

2. To use the sanitary sewerage the requirements in Title 10, CFR 20, must be met.

   Paragraph 20.303 states in subparagraph b(1) and b(2) the amount that can be released. b(2) is the larger - 1,000 µCi.

   From App C - 100 µCi x 10 = 1,000 µCi

   The material can be released directly to the sanitary sewerage without dilution provided the average monthly water sewerage rate is

$$\frac{0.1}{1 \times 10^{-3}} \quad \text{or 100 ml of water}$$

3. Maximum allowable concentration which can be eliminated through the sanitary sewerage is 5×10^{-4} µCi/ml.

   Amount to be disposed of - 1µCi.

$$\frac{1\mu Ci}{5 \times 10^{-4}} = 2{,}000 \text{ ml of water needed for dilution.}$$

   From App C - 10 µCi x 10 = 100 µCi - maximum amount that could be disposed of in 1 day.

4. Maximum allowable concentration.

$$4 \times 10^{-6}\ \mu Ci/ml$$

Amount to be disposed of

$$\frac{2500\ dps}{3.7 \times 10^{4}\ dps/\mu Ci} = \frac{2.5 \times 10^{3}}{3.7 \times 10^{4}} = 6.76 \times 10^{-2} \mu Ci$$

$$\frac{6.76 \times 10^{-2}}{4 \times 10^{-6}} = 1.69 \times 10^{4}$$

16,900 ml of water needed for dilution.

5. Given: 30,000 dpm

$$\frac{30,000\ dpm}{60 \frac{sec}{min}} = 500\ dps$$

Conversion factor: 3.7×10^{4} dps = 1μCi

$$\frac{500\ dps}{3.7 \times 10^{4} \frac{dps}{\mu Ci}} = 1.35 \times 10^{-2}\ \mu Ci$$

From App B, Footnote 2 (10 CFR 20) the maximum allowable concentration is

$$4 \times 10^{-7}\ \mu Ci/ml$$

From App C (10 CFR 20) the maximum allowable concentration for an unknown radioisotope is

$$0.1 \mu Ci.$$

From para 20.303b(2) (10 CFR 20) ten times the amount listed above, or 10 x 0.1μCi = 1μCi may be disposed of through sanitary sewerage.

The amount of water necessary to dilute the disposed radioisotope is governed by App B, Footnote 2.

$$\frac{1.35 \times 10^{-2} \mu Ci}{4 \times 10^{-7} \frac{\mu Ci}{ml}} = 3.38 \times 10^{4} \text{ ml of water.}$$

3.38×10^{4} ml of water must be dumped into the sewer in the month that the 1.35×10^{-2} µCi of radioisotope is disposed.

6. Given: $50 \mu Ci\ {}^{14}C \div (9 \times 10^{9} ml) = 5.55 \times 10^{-9} \frac{\mu Ci}{ml}$

$35 \mu Ci\ {}^{72}Ga \div (9 \times 10^{9}\ ml) = 3.9 \times 10^{-9} \frac{\mu Ci}{ml}$

$4.2\ \mu Ci\ {}^{59}Fe \div (9 \times 10^{9}\ ml) = 4.67 \times 10^{-10} \frac{\mu Ci}{ml}$

$5\ \mu Ci\ {}^{185}W \div (9 \times 10^{9}\ ml) = 5.55 \times 10^{-10} \frac{\mu Ci}{ml}$

$6\ \mu Ci\ {}^{131}I \div (9 \times 10^{9}\ ml) = 6.67 \times 10^{-10} \frac{\mu Ci}{ml}$

(Average monthly sewerage volume = 9×10^{9} ml)

From App C (10 CFR 20) allowable concentrations are seen to be greater than actual concentrations.

	Allowable	Actual
^{14}C	1,000 µCi	50 µCi
^{72}Ga	100 µCi	35 µCi
^{59}Fe	100 µCi	4.2 µCi
^{131}I	10 µCi	6 µCi
^{185}W	100 µCi	5 µCi

Therefore, the requirements of App C are satisfied.

To check for compliance with the requirements of App B:

$$\frac{C_A(^{14}C)}{MPC_A} + \frac{C_B(^{72}Ga)}{MPC_B} + \frac{C_C(^{59}Fe)}{MPC_C} + \frac{C_D(^{131}I)}{MPC_D} + \frac{C_E(^{185}W)}{MPC_E} \leq 1$$

$$\frac{5.55 \times 10^{-9}}{2 \times 10^{-2}} + \frac{3.9 \times 10^{-9}}{1 \times 10^{-3}} + \frac{4.67 \times 10^{-10}}{2 \times 10^{-3}} + \frac{6.67 \times 10^{-10}}{6 \times 10^{-5}} + \frac{5.55 \times 10^{-10}}{4 \times 10^{-3}}$$

$$= 2.77 \times 10^{-7} + 3.9 \times 10^{-6} + 2.33 \times 10^{-7} + 1.11 \times 10^{-5} + 1.39 \times 10^{-7} < 1$$

Therefore, the requirements of App B are satisfied and the material may be disposed of through the sewerage system.

RADIOLOGICAL DECONTAMINATION

DF420, RADIOLOGICAL DECONTAMINATION

I. Reference: TM 3-200, ch 4; DA Pam 39-3, para 12.71-12.75.

II. Lesson Objectives and Notes.

A. Principles of decontamination.

B. Primary methods of decontamination.

C. Preventive measures for radiological accidents.

D. Installation decontamination procedures.

Notes:

III. Handouts: DF420, Decontamination Exercise.

IV. Problems: None

V. Solutions: None

DATA SHEET FOR
DECONTAMINATION EXERCISE

Student No. ________________

Class ________________

Date ________________

I. BACKGROUND:

A. IM-141: ________________ mrad/hr
B. Scaler: ________________ c/m

II. DATA:

A. Type of Surface: ________________

B. Type of Contaminant (Dry or Wet): ________________

C. Dose Rate Readings:

1. Initial: ________________ mrad/hr

2. After blotting (wet only) ________________ mrad/hr

3. After water:

1st application ________________ mrad/hr

2d application ________________ mrad/hr

Wipe test* ________________ c/m

*Only performed if no reading above background with IM-141 radiacmeter.

4. After 5% Detergent: ________________ mrad/hr

5. After 5% Cellosolve: ________________ mrad/hr

6. After 1% Versene: ________________ mrad/hr

7. Wipe Test: ________________ c/m

8. After 1 minute scrubbing: ________________ mrad/hr

9. Wipe test after scrubbing: ________________ c/m

10. Final IM-141 reading: ________________ mrad/hr

III. CONCLUSIONS:

A. Easiest surface to decontaminate: ______________________

B. Most difficult surface to decontaminate: ______________________

C. Best decontaminant utilized: ______________________

RADIOLOGICAL DECONTAMINATION
Practical Exercise

1. Laboratory Briefing.

a. Setup. In the laboratory, each setup will consist of several contaminated surfaces and selected decontaminants and equipment. An AN/PDR-27J radiacmeter and Baird Atomic Scaler will be used for determining the background and extent of contamination.

b. Students will work in teams of three. One individual will be the decontaminator; he must wear an apron and gloves. One student will act as Radiological Safety Officer; the third student will record the group's findings on the data sheet (DF420).

c. Each group will decontaminate three contaminated surfaces. After each surface is decontaminated, individuals will change jobs so that each student functions in all three positions during the exercise.

d. The student Radiological Safety Officer will operate the radiac instrument. He will determine the background count, the extent of contamination on the surface, and contamination (if any) on the student decontaminator.

2. Laboratory Exercise.

a. Determination of background. Student in each team selected as Radiological Safety Officer (RSO) will determine background with the AN/PDR-27J and the Scaler (2 min count). The recorder will note readings on the data sheet.

b. Decontamination of wet surface.

(1) Each team selects the surface contaminated with a liquid contaminant. The RSO determines the degree of contamination with the AN/PDR-27J. (NOTE: Monitor the entire surface and note the area of greatest contamination.)

(2) Student decontaminator uses sanitary napkin to absorb excess contaminant and places napkin in waste container.

(3) RSO again monitors surface.

(4) Decontaminator applies water to contaminated area and waits 3 minutes. He then blots water with sanitary napkins.

(5) Student RSO again monitors with AN/PDR-27J.

(6) Decontaminator repeats step (4) and (5).

(7) RSO monitors surface with the AN/PDR-27J. If he detects no reading above background, the decontaminator performs a wipe test of the surface, using the brown paper swipes. The swipe should be placed in the scaler for 2 minutes; the recorder notes counts per minute and records on data sheet. If no count above background is noted, an AI will confirm the team's result. Students can then proceed to the next item and change jobs.

(8) If the count in step (7) is above background, the team repeats steps (4) through (7), using 5% detergent solution in place of water.

(9) If count remains above background after step (8), use wetting agent (5% cellosolve). If this treatment fails, repeat using 1% Versene.

(10) After decontamination with 1% Versene, the decontaminator performs another wipe test. Recorder notes counts per minute and records on data sheet.

(11) Decontaminator selects the most effective decontaminant, based on previous results, and brushes it on the surface for 1 minute. He blots the excess liquid with a sanitary napkin; the RSO then monitors with the AN/PDR-27J.

(12) Decontaminator then performs a final wipe test. Recorder notes findings on data sheet. RSO takes final reading of surface with AN/PDR-27J following wipe test.

(13) Teams select similar surface which is contaminated with a dry contaminant and repeat steps (3) through (12), unless background is obtained in prior step.

(14) Teams select third surface and repeat steps (3) through (12), unless background ~~is~~ achieved in prior step.

HEALTH PHYSICS
ENVIRONMENTAL SURVEY

DF430, HEALTH PHYSICS ENVIRONMENTAL SURVEY

I. Assignment.

Read the information below and complete the requirements.

II. Situation.

Your class has been divided into six teams, one team for each area of the USAOC&S to be surveyed. You are responsible for conducting a radiological monitoring survey in the area assigned to you. A formal report will be submitted on handout DF430.

III. Requirements.

A. During the class on Health Physics Survey, you are to conduct a radiological survey using the smear technique.

1. Proceed to the scaler laboratory; begin the background count noting the starting time and the voltage of the scaler. Allow scaler to run while conducting the survey.

2. Using the equipment furnished, pre-plan locations to be smear-tested. Locations to be numbered consecutively on diagram.

3. Proceed to assigned areas and conduct survey.

4. Return to scaler laboratory and perform scaler count (3 minutes) on smears taken. Record on handout DF430. Senior individual of team to sign as surveyor. Don't forget to record background.

5. If a smear indicates three times background or 100 cpm in excess of background contact the instructor.

6. Turn in to instructor the completed handout DF430. This is to be utilized as the file copy of the annual survey which must be conducted within the USAOC&S facilities.

B. Areas to be Surveyed.

1. Dosimetry

2. Laboratory W

3. Health Physics Office

4. Laboratory T

5. Vault

6. Isotope Laboratory

IV. Handouts: DF430, Survey Results

V. Problems: None

VI. Solutions: None

8.

SURVEY RESULTS

Smear Test.

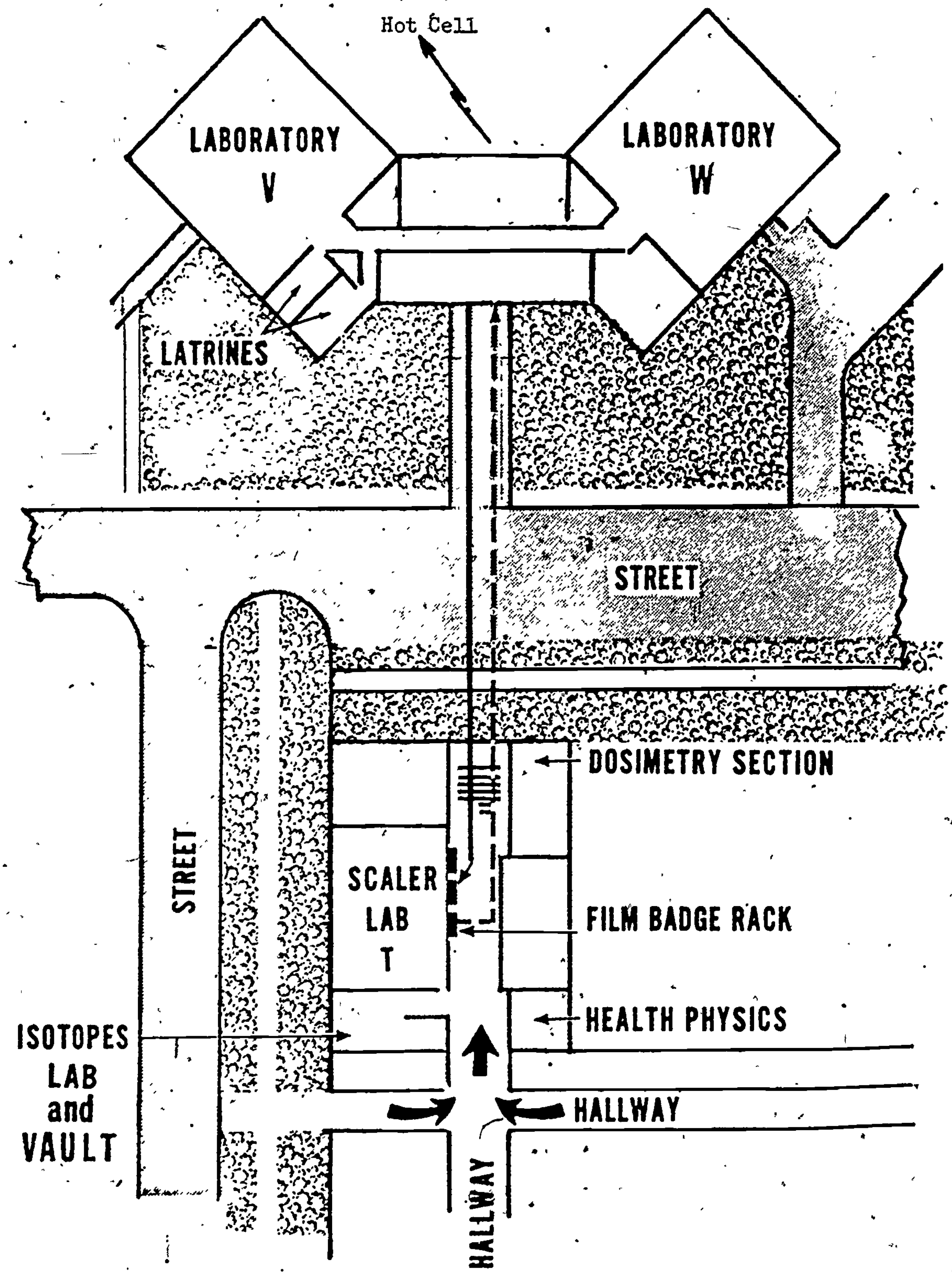
Instrument SN ______________

Background ______________ Counts ______________ Time (Min)

______________ cpm

Smear No.	Gross Counts	Time (Min)	Gross cpm	BG cpm	Net cpm
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Counted by: ______________
Surveyor



SCHEMATIC DIAGRAM OF RADIOLOGICAL LABORATORIES

RADIOLOGICAL SAFETY INVOLVING X-RAYS

DF440

DF440, RADIOLOGICAL SAFETY INVOLVING X-RAYS

I. References: None

II. Discussion and Notes:

A. Discussion.

1. Shielding.

a. Aluminum equivalent - the thickness of aluminum affording the same attenuation, under specified conditions, as the material in question.

b. Concrete equivalent - the thickness of concrete based on a density of 2.35 g/cm^3 (147 lb/ft^3) affording the same attenuation, under specified conditions, as the material in question.

c. Filter - material placed in the useful beam to absorb preferentially the less penetrating radiation.

d. Added filter - filter added to the inherent filtration.

e. Inherent filtration - filtration in the useful beam due to the window of the X-ray tube and any permanent tube enclosure.

f. Total filter - the sum of the inherent and added filters.

g. Half-value layer (hvl) - thickness of an absorber required to reduce a beam of radiation to one-half its incident exposure dose rate.

h. Lead equivalent - the thickness of lead affording the same attenuation, under specified conditions, as the material in question.

2. Shielding Barriers.

a. Protective barrier - barrier of attenuation materials used to reduce radiation exposure.

b. Primary protective barrier - barrier sufficient to attenuate the useful beam to the required degree.

c. Secondary protective barrier - barrier sufficient to attenuate stray radiation to the required degree.

3. Radiation and Radiation Hazards.

a. Radiation - energy propagated through space. In this presentation, radiation refers to X-rays.

b. Leakage radiation - all radiation coming from within the tube housing except the useful beam.

c. Scattered radiation - radiation that, during passage through matter, has been deviated in direction. It may also have been modified by a decrease in energy.

d. Stray radiation - radiation not serving any useful purpose. It includes leakage and secondary radiation.

e. Useful beam - that part of the radiation which passes through the window, aperture, cone, or other collimating device of the tube housing.

f. Radiation hazard - a condition under which persons might receive radiation in excess of the maximum permissible dose, or radiation damage might be caused to materials.

4. Beam Shielding.

a. Collimator - a device used to restrict the size of the useful beam to less than the area of the barrier.

b. Shutter - a device, generally of lead, fixed to an X-ray tube housing to intercept the useful beam.

c. Cone - a cone-shaped metal tube which absorbs the unwanted divergent rays from the X-ray beam. Its purpose is to produce a limited beam of radiation so that a specific size film is completely covered.

d. Cylinder - a cylindrically shaped metal tube which absorbs the unwanted part of the beam. The cylinder is designed to project a small beam of radiation to the center of the film.

e. Diaphragm - consists of a piece of lead with a small hole cut into it. This hole is adjustable on some diaphragms.

5. X-Ray Construction and Controls.

a. Diagnostic-type protective tube housing - X-ray tube housing so constructed that the leakage radiation at a distance of 1 meter from the target cannot exceed 100 mr/hr when the tube is operated at any of its specified ratings.

b. Therapeutic-type protective tube housing - X-ray tube housing so constructed that the leakage radiation at a distance of 1 meter from the target cannot exceed 1 rad/hr and at a distance of 5 cm from any point on the surface of the housing accessible to the patient cannot exceed 30 rad/hr when the tube is operated at any of its specified ratings.

c. Dead-man switch - a switch so constructed that a circuit closing contact can only be maintained by continuous pressure by the operator.

d. Interlock - a device for precluding access to an area of radiation hazard either by preventing entry or by automatically removing the hazard.

e. Controlled area - a defined area in which the occupational exposure of personnel to radiation or to radioactive materials is under the supervision of an individual in charge of radiation protection.

f. Radiation protection survey - evaluation of the radiation hazards in and around an installation. It customarily includes a physical survey of the arrangement of the exposure rates under expected operating conditions.

6. Terminology Used in Operations.

a. Constant potential - this term is applied to a unidirectional potential (or voltage) which has little or no periodic variation. The periodic component is called the ripple potential (or ripple voltage).

b. FOS - distance from focal spot to skin surface of patient.

c. Kilovolt peak (kvp) - the crest value in kilovolts of the potential of a pulsating potential generator. When only one-half of the wave is used the value refers to the useful half of the wave.

d. Milliampere (ma) - current flowing in the tube. Most X-ray machines are operated at, or above, the saturation current of the tube. The saturation current is the maximum current which will flow from the cathode to the anode (measured in ma) regardless of kvp applied. The kv may be varied independently of the ma, and the ma may be charged independently of the kv.

e. Occupancy factor (T) - the factor by which the workload should be multiplied to correct for the degree or type of occupancy of the area in question.

f. Use factor (U) - the fraction of the workload during which the useful beam is pointed in the direction under consideration.

g. Workload (W) - the use of an X-ray machine expressed in milliampere minutes per week.

7. X-Ray Production.

a. Source of electrons must be available.

b. Means of very rapidly speeding up (accelerating) these electrons.

c. Means of very suddenly stopping the electrons.

8. Radiographic Installations.

a. Useful beam pointed mainly toward the radiographic table and chest cassette holder.

b. Protective enclosure so located that X-ray technician can observe and communicate with patient.

c. Lead glass window sufficient size (not less than 10" x 12"). Center of lead glass 60" from floor.

d. X-ray control booth accommodates the X-ray control and X-ray technician. Technician can locate in front of the lead glass window.

9. Structural Detail of Protective Barriers.

a. 1/16" sheet lead if the required lead equivalent thickness is not provided by existing wall or floor structure.

b. No sag or cold-flow of lead shielding because of their own weight.

c. Joints in barrier lap at least ½".

d. Welded or burned seams not less than barrier requirement.

e. Windows, window frames, doors, and door frames same lead equivalent as adjacent wall.

f. Holes in barrier covered so overall attenuation is the same.

g. Louvers and holes for conduits, air ducts, etc, provided baffles to waive some attenuation.

10. Radiographic Equipment.

a. The tube housing should be of diagnostic type.

b. Diaphragms or cones should be provided for collimating the useful beam and should provide the same degree of protection as that required of the housing.

c. The total filtration permanently in the useful beam should be not less than 2.5 of aluminum equivalent. This requirement may be assumed to have been met if the hvl is not less than 2.5 mm aluminum at normal operating voltages. The tube may be assumed to have an inherent filtration of 0.5 mm aluminum equivalent.

d. A dead-man type of exposure switch should be provided and so arranged that it cannot be conveniently operated outside a shielded area. Exposure switches for "spot-film" devices used in conjunction with fluoroscopic tables are excepted from this shielding requirement.

11. Structural Shielding.

a. All inside walls and doors should have a lead equivalent thickness of 1/16" to a height of 7 feet.

b. The floor should have a lead equivalent thickness of 1/16" if the area below the radiographic room is or could be occupied.

c. The ceiling should have a lead equivalent thickness of 1/32" if the area above the radiographic room is or could be occupied.

d. If the chest cassette holder is located against the outside wall and the area within 50 feet beyond the outside wall is occupied, the wall behind the chest cassette holder should have a lead equivalent thickness of 1/16". This area should extend from the floor to a height of 7 feet and extend 2 feet beyond the sides of the cassette holder.

e. The X-ray control cabinet should be located in an adjacent room or in a shielded booth within the same room. The control booth should be so arranged that the radiation has to be scattered at least twice before entering the booth. The lead equivalent thickness of the booth wall should be 1/16".

f. An observation window having a lead equivalent thickness of 1/16" should be provided in the control booth wall for the X-ray technician. The window should provide a convenient, unobstructed view of ~~all~~ areas within the radiographic rooms where a patient may be placed for radiography.

12. Other Items of Interest.

a. Lead Equivalents.

Lead	1/16 inch	1/32 inch
Brick	$6\frac{1}{4}$	$3\frac{1}{2}$
Granite	$4\frac{1}{2}$	$2\frac{1}{2}$
Limestone	5	2 3/4
Marble	$4\frac{1}{4}$	$2\frac{1}{2}$
Sand plaster	$7\frac{1}{2}$	$4\frac{1}{4}$
Sandstone	$5\frac{1}{4}$	3
Siliceous concrete	5	2 3/4
Tile	$6\frac{1}{4}$	$3\frac{1}{2}$

b. Radiation Protection Standards.

	Average weekly dose*	13-week dose	Maximum yearly dose	Maximum accumulated dose**
	r	r	r	r
Radiation workers:				
Whole body, gonads, blood-forming organs, and lens of eye	0.1	1.25	--	5(N-18)
Skin of whole body	--	10	30	--
Hands and fore-arms, head, neck, feet, and ankles	--	25	75	--
Environs (non-radiation workers):				
Any part of body	.01	--	0.5	--

NOTES:

N - age in years over 18
* For design purposes only.
** When the previous occupational exposure history of an individual is not definitely known, it shall be assumed that he has already received the full dose permitted by the formula 5(N-18).

c. Dental Unit Output.

kvp	Target skin distance	Total	r/ma-min	r/ma-sec
	Inches	mm Al		
50	4	1.5	12	0.20
70	8	1.5	8.3	0.14
70	16	1.5	2.1	0.03
90	8	2.5	8.4	0.14

d. Exposure Distances.

Circular area around the beam when perpendicular to the table top where occupancy is to be prevented. 100 mr/wk levels are given for radiation workers and 10 mr/wk levels are given for non-radiation workers.

Weekly workload	Radiation workers radius for 100 mr/wk	Non-radiation workers radius for 10 mr/wk
1500 mam	10 feet	30 feet
1000 mam	7.5 feet	22.5 feet
500 mam	5 feet	14 feet

mam = milliamperes minutes

Wedge area of the beam in lateral radiography in which occupancy is to be prevented. 100 mr/wk levels are given for radiation workers and 10 mr/wk levels for non-radiation workers.

Weekly workload		Radiation workers 100 mr/wk	Non-radiation workers 10 mr/wk
mam	mas		
150	9000	50 feet	120 feet
100	6000	44 feet	105 feet
50	3000	32 feet	70 feet
25	1500	--------	62 feet
10	600	--------	44 feet
5	300	--------	32 feet

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

X-RAY PROTECTION SURVEY REPORT
FACILITY

FORM APPROVED
BUDGET BUREAU NO 68-R901

1 NAME OF FACILITY

2 TELEPHONE

3 NUMBER ASSIGNED BY AGENCY [ ] [ ] [ ] [ ] [ ] [ ] (1 2 3 4 5 6)

4 LOCATION (Street, Building, Room Number)

7 STATE [ ] [ ] (18 19) COUNTY [ ] [ ] [ ] (20 21 22) CITY [ ] [ ] [ ] [ ] (23 24 25 26) ZIP CODE

5 DATE (Mo., Day, Yr.) [ ] [ ] [ ] [ ] [ ] [ ] (7 8 9 10 11 12)

6 CARD I D [1] [ ] [ ] [ ] [ ] (13 14 15 16 17)

8 PERSON IN CHARGE OF X-RAY FACILITY

9 PERSON RESPONSIBLE FOR RADIATION SAFETY: NAME TITLE

10 PERSON INTERVIEWED: POSITION

11 PREVIOUS RADIATION SAFETY SURVEY 1.___ Yes 2.___ No
BY WHOM DATE:

12 TYPE OF FACILITY 1.___ Private Office 2.___ Hospital 3.___ Clinic
4.___ Mobile 5.___ Other (Specify)

13 TYPE OF PRACTICE:

14 PERSONNEL

A. TOTAL NUMBER OCCUPATIONALLY EXPOSED ____________ A [ ] [ ] (31 32)

B. TOTAL NUMBER OF OPERATORS ____________ [ ] [ ] (33 34) C. TOTAL NUMBER MONITORED ____________ C [ ] [ ] (35 36)

D MONITORING SYSTEM EMPLOYED 0.___ Never or none 1.___ Currently
2.___ Within past year 3.___ Not within past year D [ ] (37)

E MONITORING SYSTEM ADEQUATE: 1.___ Yes 2.___ No 3.___ N/A E [ ] (38)

F. MONITORING RECORDS SATISFACTORY 1.___ Yes 2.___ No 3.___ N/A F [ ] (39)

G. LEVELS/MONTH ______ Maximum MR. H NUMBER OVER 300 MR QUARTER ______ H [ ] (40)

15 "WORKLOAD"

A. PATIENTS RADIOGRAPHED (Average per week) ____________ A [ ] [ ] [ ] [ ] (41 42 43 44)

B. PATIENTS FLUOROSCOPED (Average per week) ____________ B [ ] [ ] [ ] (45 46 47)

C. THERAPY TREATMENTS (Average per week) ____________ C [ ] [ ] [ ] (48 49 50)

16 EQUIPMENT

A TOTAL NUMBER OF MACHINES AT THIS FACILITY ____________ A [ ] [ ] (51 52)

B TOTAL NUMBER OF UNITS (Tubes) ____________ B [ ] [ ] (53 54)

17 FILM AND SCREEN

A. BRAND AND TYPE OF X-RAY FILM USED ____________ A [ ] [ ] (55 56)

B TYPE OF INTENSIFYING SCREEN ____________ B [ ] [ ] (57 58)

18 DARKROOM PROCEDURE

A. DARKROOM LIGHT TIGHT: 0.___ No darkroom 1.___ Yes 2.___ No A [ ] (59)

B. TYPE OF DEVELOPER: ____________ B [ ] [ ] (60 61)

C. AUTOMATIC PROCESS 1.___ Yes 2.___ No C [ ] (62)

D. HOW OFTEN CHANGED (Weeks) ______ [ ] [ ] (63 64) E. HOW OFTEN REPLENISHED (Days) ______ E [ ] [ ] (65 66)

F. THERMOMETER PRESENT: 1.___ Yes 2.___ No 3.___ Thermostatically controlled F [ ] (67)

G. TEMPERATURE INDICATED ______ °F [ ] [ ] (68 69) H. TIMER PRESENT: 1.___ Yes 2.___ No [ ] (70)

I. TIME IN DEVELOPER (Minutes) ____________ [ ] [ ] (71 72)

19 RADIOACTIVE MATERIALS

A. RADIUM EVER PRESENT: 1.___ Yes 2.___ No A [ ] (73)

B. OTHER ISOTOPES EVER PRESENT: 1.___ Yes 2.___ No B [ ] (74)

20 REASON FOR SURVEY

1.___ Initial 2.___ Follow-up 3.___ Resurvey
4.___ Request 5.___ Complaint 6.___ Other (Specify) [ ] (75)

21 SURVEYORS A. ____________ B. ____________

PHS-4495-1 (REV. 10-67)

(Use reverse side for remarks or sketch)

WORKLOAD (Ma-Min/wk) ________ SHIELDING INFORMATION MAX. KVP ________

LOCATION	COMPOSITION AND THICKNESS	ENVIRONS OR CONTROL	PRIMARY OR SECONDARY	USE X OCCUPANCY	TARGET TO WALL DISTANCE	N.B.S. REQUIRED BARRIER	ADDITIONAL SHIELDING REQUIRED
NORTH (Top)							
EAST (Right)							
SOUTH (Bot.)							
WEST (Left)							
ABOVE							
BELOW							

SKETCH OF FACILITY AND/OR REMARKS

(Indicate scale used)

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

X-RAY PROTECTION SURVEY REPORT RADIOGRAPHIC

FORM APPROVED
BUDGET BUREAU NO. 68-R808

1. NAME OF FACILITY
2. TELEPHONE
3. NUMBER ASSIGNED BY AGENCY (1 2 3 4 5 6)
4. LOCATION (Street, Building, Room Number)
7. STATE COUNTY CITY ZIP CODE
5. DATE (Mo., Day, Yr.) (7 8 9 10 11 12)
6. CARD I.D. 2 (13 14 15 16 17)
(18 19) (20 21 22) (23 24 25 26)

EQUIPMENT IDENTIFICATION

A. NUMBER ASSIGNED MACHINE

B. CONTROL PANEL MANUFACTURER — B (27 28)

C. TUBE HEAD MANUFACTURER AND MODEL — C (29 30)

D. COMBINATION 1. ___ Yes 2. ___ No — D (31)

E. TYPE: 1. ___ Fixed Radiographic (indicate special type) — E (32)
2. ___ Photofluorographic 3. ___ Mobile 4. ___ Other (specify)

F. NUMBER OF TUBES (33) G. MAXIMUM KVP (RATED) (34 35 36) H. MAXIMUM MA (RATED) (37 38 39)

9. **FILTRATION**

A. TOTAL MM. ALUMINUM EQUIVALENT A. BEFORE (40 41) B. AFTER (42 43)

10. **"WORKLOAD"**

A. AVERAGE NUMBER OF PATIENTS PER WEEK (estimate) — A (44 45 46)

B. TOTAL NUMBER OF EXPOSURES PER WEEK (estimate)

11. **USUAL PROCEDURES**

EXAMINATION (specify)	KVP	MA / TIME	MAS	EXPOSURES PER WK.	FILM SIZE	DISTANCE (inches)	BEAM TYPE	BEAM SIZE (inches)	COLLIMATION
1. (47)	(48 49 50)		(51 52 53)		(54)	(55 56)	(57)	(58 59)	(60)
2. (61)	(62 63 64)		(65 66 67)		(68)	(69 70)	(71)	(72 73)	(74)
3.									

12. **EXPOSURE SWITCH**

A. ADEQUATE LOCATION 1. ___ Yes 2. ___ No — A (75)

13. **TIMER**

A. ADEQUATE: 1. ___ Yes 2. ___ No — A (76)

14. **PROTECTIVE DEVICES**

A. GONADAL SHIELD FOR PATIENT: 1. ___ Yes 2. ___ No 3. ___ N/A — A (77)

B. ADEQUATE OPERATOR PROTECTION: 1. ___ Yes 2. ___ No — B (78)

C. ADEQUATE PRIMARY AND SECONDARY BARRIERS: 1. ___ Yes 2. ___ No 3. ___ N/A — C (79)

D. DIAGNOSTIC-TYPE TUBE HOUSING: 1. ___ Yes 2. ___ No — D (80)

15. **STRAY RADIATION MEASUREMENTS**

POSITION	EXPOSURE RATE MR/HR	POSITION	EXPOSURE RATE MR/HR
A. OPERATOR		D.	
B.		E.	
C.		F.	

(MAXIMUM READINGS TAKEN AT KVP ______ MA ______ SECONDS ______)

16. **SURVEYORS** A. ______ B. ______

PHS-4495-3 (REV. 10-67)

(Use reverse side for remarks or sketch)

WORKLOAD (Ma-Min/wk) ________ SHIELDING INFORMATION MAX. KVP ________

LOCATION	COMPOSITION AND THICKNESS	ENVIRONS OR CONTROL	PRIMARY OR SECONDARY	USE X OCCUPANCY	TARGET TO WALL DISTANCE	N.B.S. REQUIRED BARRIER	ADDITIONAL SHIELDING REQUIRED
NORTH (Top)							
EAST (Right)							
SOUTH (Bot.)							
WEST (Left)							
ABOVE							
BELOW							

SKETCH OF RADIOGRAPHIC ROOM AND/OR REMARKS

(Indicate scale used)

PHS-4495-3 (BACK)
REV. 10-67

DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

X-RAY PROTECTION SURVEY REPORT
FLUOROSCOPIC

FORM APPROVED
BUDGET BUREAU NO. 68-R608

1. NAME OF FACILITY
2. TELEPHONE
3. NUMBER ASSIGNED BY AGENCY — 1 2 3 4 5 6
4. LOCATION (Street, Building, Room Number)
7. STATE — COUNTY — CITY — 18 19 · 20 21 22 · 23 24 25 26
5. DATE (Mo., Day, Yr.) — 7 8 9 10 11 12
6. CARD I.D. — 3 — 13 14 15 16 17

8. EQUIPMENT IDENTIFICATION

A. NUMBER ASSIGNED MACHINE ______ B 27 28
B. CONTROL PANEL MANUFACTURER ______ C 29 30
C. TUBE HEAD MANUFACTURER AND MODEL ______
D. COMBINATION: 1. ___ Yes 2. ___ No — D 31
E. TYPE: 1. ___ Vertical 2. ___ Horizontal 3. ___ Tilting Table 4. ___ Other — E 32
F. IMAGE INTENSIFYING DEVICE USED: 1. ___ Yes 2. ___ No — F 33
G. OTHER IDENTIFICATION (Specify)

9. ACCESSORY SHIELDING

A. LEADED GLOVES: 1. ___ Yes 2. ___ No — 34
B. LEADED APRON: 1. ___ Yes 2. ___ No — B 35
C. BUCKY SLOT COVER. 1. ___ Yes 2. ___ No 3. ___ N/A — C 36
D. LEADED DRAPES AROUND SCREEN: 1. ___ Yes 2. ___ No 3. ___ N/A — D 37
E. OTHER (Specify)

10. DARK ADAPTATION

A. GOGGLES USED: 1. ___ Yes 2. ___ No
B. NUMBER OF MINUTES: ______ — B 38 39

11. USUAL PROCEDURES

EXAMINATION	KVP	MA	MINUTES TUBE ACTIVATED PER EXAMINATION	EXAMINATIONS PER WEEK
A. UPPER G. I.	40 41 42	43 44	45	46 47
B. LOWER G.I.	48 49 50	51 52	53	54 55
C. OTHER (Specify)				56 57
D. TOTAL MA-MIN/ WEEK				58 59 60

12. SPOT FILMS

A. AVERAGE EXPOSURES PER WEEK: ______ — 61 62 63

13. SCREEN

A. FLUOROSCOPIC SCREEN GANGED TO X-RAY TUBE: 1. ___ Yes 2. ___ No — A 64
B. LEADED GLASS SATISFACTORY: 1. ___ Yes 2. ___ No 3. ___ N/A — B 65
C. SHUTTERS FUNCTION PROPERLY: 1. ___ Yes 2. ___ No 3. ___ Fixed — C 66
D. USEFUL BEAM LIMITED TO SCREEN: 1. ___ Yes 2. ___ No — D 67
Overlap: ___ Top ___ Right ___ Bottom ___ Left

14. DISTANCE

A. TARGET TO PANEL (Inches): ______ — A 68 69

15. ROENTGEN OUTPUT

A. USEFUL BEAM AT PANEL SURFACE: ______ R/MIN. — A 70 71 72

16. FILTRATION

A. TOTAL MM. ALUMINUM EQUIVALENT: A. Before 73 74 — B. After 75 76

17. TIMER

A. DEADMAN TYPE EXPOSURE SWITCH: 1. ___ Yes 2. ___ No — A 77
B. MANUALLY RESET CUMULATIVE TIMER: 1. ___ Yes 2. ___ No — B 78
C. CUMULATIVE TIMER TERMINATES EXPOSURE 1. ___ Yes 2. ___ No — C 79

18. FLUOROSCOPIC ROOM

A. LIGHT TIGHT: 1. ___ Yes 2. ___ No 3. ___ N/A — A 80

19. STRAY RADIATION MEASUREMENTS

POSITION	EXPOSURE RATE (MR/HR)	POSITION	EXPOSURE RATE (MR/HR)
A. OPERATOR		D.	
B. ABOVE SCREEN		E.	
C.		F.	

(MAXIMUM READINGS TAKEN AT KVP ______ MA ______ SECONDS ______)

20. SURVEYORS A. ______ B. ______

PHS-4495-2 (REV. 7-65)

(Use reverse side for remarks or sketch)

670

WORKLOAD (Ma-Min/wk) ________, SHIELDING INFORMATION MAX. KVP ________

LOCATION	COMPOSITION AND THICKNESS	ENVIRONS OR CONTROL	PRIMARY OR SECONDARY	USE X OCCUPANCY	TARGET TO WALL DISTANCE	N.B.S. REQUIRED BARRIER	ADDITIONAL SHIELDING REQUIRED
NORTH (Top)							
EAST (Right)							
SOUTH (Bot.)							
WEST (Left)							
ABOVE							
BELOW							

SKETCH OF FLUOROSCOPIC ROOM AND/OR REMARKS

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

RADIATION PROTECTION SURVEY REPORT
THERAPEUTIC

FORM APPROVED
BUDGET BUREAU NO. 68-R966

1 NAME OF FACILITY	2 TELEPHONE	3. NUMBER ASSIGNED BY AGENCY (1 2 3 4 5 6)
4 LOCATION (Street, Building, Room Number)	7 STATE (18 19)	COUNTY (20 21 22) CITY (23 24 25 26) ZIP CODE
5. DATE (Mo., Day, Yr.) (7 8 9 10 11 12)	6 CARD I D 4 (13 14 15 16 17)	

8 EQUIPMENT IDENTIFICATION

A NUMBER ASSIGNED UNIT ______ B. RADIATION SOURCE ______ (27) C UNIT MANUFACTURER ______ (28 29)

D. TYPE OF UNIT: 1. ☐ Superficial 2. ☐ Deep 3 ☐ Supervoltage 4. ☐ Teletherapy 5. ☐ Other (Specify) ______ (30)

9 "WORKLOAD"

A AVERAGE TIME PER TREATMENT (MIN.) ______ (31 32)

B. AVERAGE NUMBER OF TREATMENTS PER WEEK ______ (33 34 35)

X-RAY

C MAXIMUM kVp USED ______ (36 37 38 39)

D MAXIMUM mA USED ______ (40 41)

E. AVERAGE mAm PER WEEK ______ (42 43 44 45)

ISOTOPE

F STRENGTH OF RADIONUCLIDE (RHM) ______ (46 47 48 49)

G. ROENTGENS PER WEEK AT ONE METER ______ (50 51 52 53)

10 FILTRATION

A FILTER IDENTIFICATION SYSTEM	1. ☐ Yes	2. ☐ No	3. ☐ N/A	A	54
B SECURE FILTER SLOT	1. ☐ Yes	2. ☐ No	3. ☐ N/A	B	55

11. COLLIMATION

A SHUTTER POSITION INDICATED AT CONTROL	1. ☐ Yes	2. ☐ No	3. ☐ N/A	A	56
B VARIOUS PORT SIZES AVAILABLE	1. ☐ Yes	2. ☐ No	3. ☐ N/A	B	57
C. LEAD RUBBER, FOIL, ETC., TO LIMIT FIELD	1. ☐ Yes	2. ☐ No	3. ☐ N/A	C	58

12. PROTECTIVE QUALITIES AND DESCRIPTIVE INFORMATION

A TYPE OF TREATMENT	1. ☐ Stationary	2. ☐ Rotational		A	59
B. ADEQUATE INTERLOCK SYSTEM	1. ☐ Yes	2. ☐ No	3. ☐ N/A	B	60
C. MANUALLY RESET CUMULATIVE TIMER	1. ☐ Yes	2. ☐ No	3. ☐ N/A	C	61
D. TIMER TERMINATES EXPOSURE	1. ☐ Yes	2. ☐ No	3. ☐ N/A	D	62
E. PATIENT AND CONTROL OBSERVED SIMULTANEOUSLY	1. ☐ Yes	2. ☐ No	3. ☐ N/A	E	63
F PATIENT-OPERATOR COMMUNICATION AVAILABLE	1. ☐ Yes	2. ☐ No	3. ☐ N/A	F	64
G RADIATION AREA POSTED	1. ☐ Yes	2. ☐ No	3. ☐ N/A	G	65
H PRIMARY BEAM SHIELD PRESENT	1. ☐ Yes	2. ☐ No	3. ☐ N/A	H	66
I. CONTROL PANEL LOCKED WHEN NOT IN USE	1. ☐ Yes	2. ☐ No	3. ☐ N/A	I	67
J. SOURCE CALIBRATED ANNUALLY	1. ☐ Yes	2. ☐ No	3. ☐ N/A	J	68
DATE OF LAST CALIBRATION ______					
K. THERAPEUTIC TYPE PROTECTIVE SOURCE HOUSING	1. ☐ Yes	2. ☐ No	3. ☐ N/A	K	69
L. PRIMARY AND SECONDARY BARRIERS ADEQUATE	1. ☐ Yes	2. ☐ No	3. ☐ N/A	L	70
M. ADEQUATE OPERATOR PROTECTION	1. ☐ Yes	2. ☐ No	3. ☐ N/A	M	71
N. BEAM MONITORING DEVICE	1. ☐ Yes	2. ☐ No	3. ☐ N/A	N	72
O. EMERGENCY PROCEDURES POSTED	1. ☐ Yes	2. ☐ No	3. ☐ N/A	O	73
P LEAK TEST PERFORMED	1. ☐ Yes	2. ☐ No	3. ☐ N/A	P	74
DATE OF LAST TEST ______					

13. SURVEYORS A ______ B. ______

PHS-4495-7 (REV. 2-67) (Use reverse side for sketch and/or remarks)

RADIATION MEASUREMENTS TAKEN AT ________ kV ________ FIELD SIZE ________ FILTER ________

LOCATION OF MEASUREMENTS	SKETCH POSITION	HEIGHT OF INSTRUMENT ABOVE FLOOR (IN FEET)	BEAM DIRECTION (IN DEGREES)	PHANTOM YES	PHANTOM NO	mR/HOUR	REMARKS

15. SKETCH AND/OR REMARKS

16. SHIELDING INFORMATION

WORKLOAD (mAmin/wk) ________ MAX. kVp ________

LOCATION	COMPOSITION AND THICKNESS	ENVIRON OR CONTROL	PRIMARY OR SECONDARY	USE (X) OCCUPANCY	TARGET TO WALL DISTANCE	N.B.S. REQUIRED BARRIER	ADDITIONAL SHIELDING REQUIRED
NORTH (Top)							
EAST (Right)							
SOUTH (Bot.)							
WEST (Left)							
ABOVE							
BELOW							

PHS-4495-7 (BACK)
REV. 2-67

PHYSICAL RADIATION PROTECTION SURVEY OF DENTAL X-RAY EQUIPMENT INSTALLATION CARD NO. 1

2. STATE, COUNTY, CITY — 1 2 3 4 5 6 7 8

3. DENTIST, CARD IDENTIFICATION — 9 10 11 12 13 14 15

1\.
A. ______ NAME OF USER(S)
B. ______ INSTALLATION ADDRESS
C. ______ PHONE NUMBER
D. ______ CITY
E. ______ COUNTY
F. ______ STATE ______ ZIP CODE
G. ______ NAME OF SURVEYOR

4\. TOTAL X-RAY UNITS AT INSTALLATION — 16

5\. X-RAY UNIT IDENTIFICATION NUMBER — 17

6\. NUMBER OF PERSONS OPERATING THIS UNIT — 18

7\. NUMBER OF OFFICE PERSONNEL
A. FULL TIME DENTISTS — 19
B. PART TIME DENTISTS — 20
C. OTHER FULL TIME PERSONNEL — 21
D. OTHER PART TIME PERSONNEL — 22

8\. TYPE OF PRACTICE
1. GENERAL ______
2. ORAL SURGERY ______
3. ORTHODONTIC ______
4. PEDODONTIC ______
5. PERIODONTIC ______
6. PROSTHODONTIC ______
7. MORE THAN ONE TYPE ______
9. OTHER (SPECIFY) ______
— 23

9\. X-RAY UNIT
A MANUFACTURER ______ MODEL ______ — 24 25
B TUBE SERIAL NUMBER ______ — 26 27 28 29 30 31 32 33 34
C CONSOLE SERIAL NUMBER ______ — 35 36 37 38 39 40 41 42

10\. POINTER CONE
0 NONE ______
1 SHORT POINTED ______
2 SHORT OPEN ______
3 LONG POINTED ______
4 LONG OPEN ______
9. OTHER (SPECIFY) ______
— 43

11\. FIELD DIAMETER AT END OF POINTER CONE (inches)
A BEFORE MODIFICATION ______ — 44 45 46
B AFTER MODIFICATION ______ — 47 48 49

12\. TOTAL FILTRATION OF PRIMARY BEAM (mm Al equiv.)
A BEFORE MODIFICATION ______ — 50 51 52
B AFTER MODIFICATION ______ — 53 54 55

13\. ROENTGEN OUTPUT AT END OF POINTER CONE IN r/sec.
A BEFORE MODIFICATION ______ — 56 57 58
B. AFTER MODIFICATION ______ — 59 60 61

14\. IS X-RAY UNIT OPERABLE AT LEAST 6 FEET FROM TUBE HEAD
0 NO ______ 1 YES ______ — 62

15\. TIME
SURVEY BEGAN ______ SURVEY ENDED ______ DIFFERENCE IN MINUTES — 63 64

16\. DATE OF SURVEY
(MONTH/DAY/YEAR) ______ — 65 66 67 68

17\. FURTHER CONSULTATION RECOMMENDED
0 NO ______ 1 YES (SEE REMARKS) ______ — 69

18\. CODE NUMBER OF SURVEYOR — 70 71

PHS 3657 1
REV 1-67

Form Approved
Budget Bureau No. 50-R733

CARD NO. 2	IDENTIFICATION																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

19. TIMER

A. TYPE 0. NONE ____ 1 MECHANICAL ____ 2. ELECTRICAL OR ELECTRONIC ____ 18

B. TERMINATES EXPOSURE ?

0. NO ____ 1 YES ____ 3 UNKNOWN ____ 19

C. STOPWATCH CHECK

TIMER SETTING ____ STOPWATCH READING ____ DIFFERENCE 20

20. X-RAY UNIT GROUNDED

0 NO ____ 1 YES ____ 3. UNKNOWN ____ 21

21. STABILITY OF TUBE HEAD

0 ADEQUATE ____ 1 NOT ADEQUATE ____ 22

22. TUBE HOUSING RADIATION LEAKAGE WITHIN RECOMMENDED STANDARDS

0. NO ____ 1 YES ____ 23

23. PROTECTIVE BARRIERS

0 NONE ____

1 FIXED WITH LEAD WINDOW ____
2 FIXED WITH NO LEAD WINDOW ____
3 MOBILE WITH LEAD WINDOW ____
4. MOBILE WITH NO LEAD WINDOW ____
5 PRESENT BUT NOT IN USE ____
9 OTHER (SPECIFY) ____ 24

24. LEAD APRONS

0 NONE ____

1 OPERATOR ONLY ____
2 PATIENT ONLY ____
3 BOTH OPERATOR AND PATIENT ____
4 PRESENT BUT NOT IN USE ____ 25

25. PERSONNEL MONITORING

A. TYPE

0 NONE ____
1. FILM BADGE ____
2. POCKET CHAMBER ____
3. POCKET DOSIMETER ____
4 DENTAL FILM ____
9. OTHER (SPECIFY) ____ 26

B. TIME

0 NONE ____
1. CURRENTLY BEING USED ____
2 WAS USED WITHIN THE PAST 12 MOS ____
3. WAS USED OVER ONE YEAR AGO ____ 27

C. RESULTS

0 NONE ____
1. UNDETERMINED ____
2. BELOW 25 mr/wk ____
3. 25 TO 100 mr/wk ____
4. ABOVE 100 mr/wk ____ 28

26. WORKLOAD

A. ESTIMATED NUMBER OF FILMS PER WEEK ON THIS UNIT ____ 29 30 31

B AVERAGE EXPOSURE TIME PER FILM OF UPPER FIRST MOLAR ____ 32 33 34

C. CALCULATED AVERAGE EXPOSURE TIME PER FILM (in seconds) ____ 35 36 37

(AVG. EXP. - UP MOLAR X .7)

D. USUAL MILLIAMPERES ____ 38 39

E. MILLIAMPERE-SECONDS PER WEEK ____ 40 41 42 43

F. USUAL KILOVOLTAGE ____ 44 45

27. FILM USED

A. BITEWING

MANUFACTURER ____ TYPE OR CODE ____ 46 47

B. PERIAPICAL

MANUFACTURER ____ TYPE OR CODE ____ 48 49

LIST OTHER FILMS UNDER REMARKS

28. DARKROOM PROCEDURES

A DEVELOPER USED

MANUFACTURER ____ TYPE ____ 50 51

B. USUAL DEVELOPMENT TIME (in minutes) ____ 52 53

C. USUAL TEMPERATURE OF DEVELOPER (in degrees fahrenheit) ____ 54 55

D. THERMOMETER IN DARKROOM

0. NO ____
1. YES ____
2. THERMOSTATIC CONTROL ____
3. NO DARKROOM ____ 56

E. USUAL CHANGE OF DEVELOPER (in weeks) ____ 57 58

F. IS DARKROOM LIGHT TIGHT

0. NO ____ 1. YES ____ 59

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REV. 1-67 (PAGE 2)

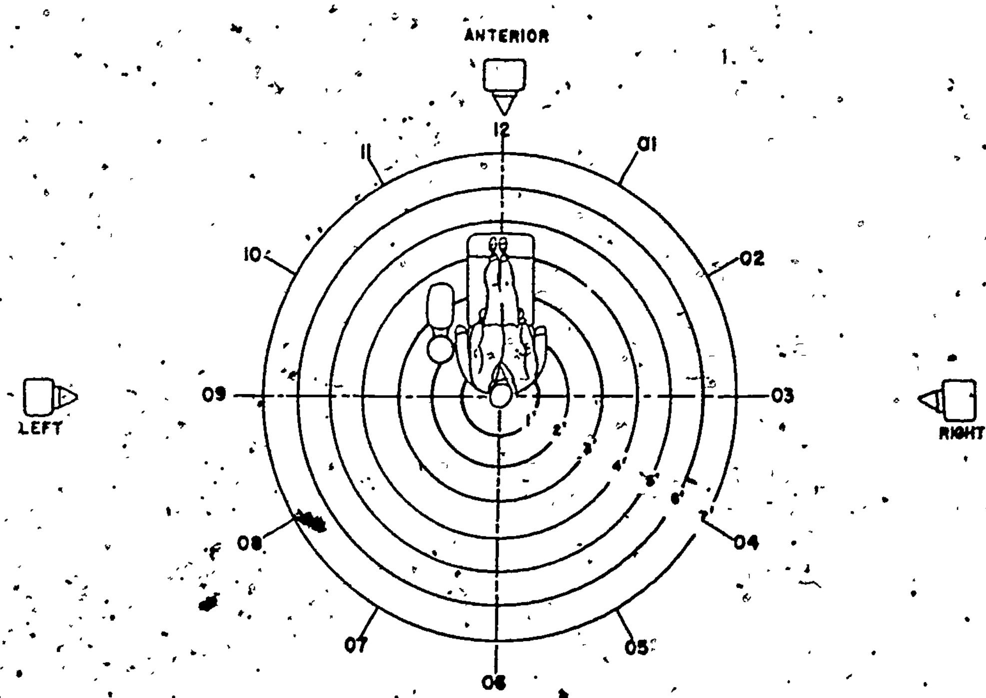
CARD NO. 3

IDENTIFICATION

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

29. OCCUPATIONAL EXPOSURE; SCATTER RADIATION (REFER TO DIAGRAM BELOW).

	AT NORMAL OPERATING POSITION: DIRECTION		DISTANCE	mr/hr				AT NEW POSITION: mr/hr		
I LEFT BITEWING EXPOSURE										
A. DENTIST	18	19	20	21	22	23	24	25	26	27
B. ASSISTANT	28	29	30	31	32	33	34	35	36	37
II ANTERIOR UPPER PERIAPICAL EXPOSURE										
C. DENTIST	38	39	40	41	42	43	44	45	46	47
D. ASSISTANT	48	49	50	51	52	53	54	55	56	57
III RIGHT BITEWING EXPOSURE										
E. DENTIST	58	59	60	61	62	63	64	65	66	67
F. ASSISTANT	68	69	70	71	72	73	74	75	76	77



30.

TYPE OF SURVEY INSTRUMENT USED ______________________ 78

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NOTE TIME SURVEY ENDED

676

CARD NO. 4	IDENTIFICATION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

31. BEAM QUALITY DETERMINATION (CAP ON/CAP OFF METHOD)

A. KVP FOR THIS EXPOSURE ______ (18 19)

B. MA FOR THIS EXPOSURE ______ (20 21)

C. CHAMBER A CAP OFF — TIME IN SECONDS ______ NUMBER OF ROENTGENS ______ ROENTGENS/SEC (22 23 24)

D. CHAMBER B CAP OFF — TIME IN SECONDS ______ NUMBER OF ROENTGENS ______ ROENTGENS/SEC (25 26 27)

E. CHAMBER A CAP ON — TIME IN SECONDS ______ NUMBER OF ROENTGENS ______ ROENTGENS/SEC (28 29 30)

F. CHAMBER B CAP OFF — TIME IN SECONDS ______ NUMBER OF ROENTGENS ______ ROENTGENS/SEC (31 32 33)

G. RATIO, CAP ON / CAP OFF — CHAMBER A ______ (34 35 36)

H. HALF VALUE LAYER CALCULATED ______ (37 38 39)

I. TOTAL ALUMINUM EQUIVALENT FILTRATION ______ (40 41 42)

31. REMARKS

(1) Does Dentist or Assistant Hold Patients or Film During Exposure? Yes ____ No ____

(2) Does Dentist and Assistant Stand 6' from Patient or Behind a Protective Barrier? Yes ____ No ____

(3) Does Dentist or Assistant Hold Cone or Tube? Yes ____ No ____

(4) Is Fluoro. Ever Used? Yes ____ No ____

Comments:

III. Laboratory Exercise: None

IV. Problems: None

V. Solutions: None

LASERS
OPERATION AND SAFETY

DF450

Student Performance Objectives.

A. Have a knowledge of the operation of a standard laser system to include knowledge of the components of a laser system.

B. Have a knowledge of the hazards associated with laser use and the RPO's responsibilities for evaluating these hazards.

C. Be aware of the agencies available to aid the post RPO in his hazard evaluation duties, and the procedures necessary to obtain their assistance.

Contents

APPENDIX A

INTRODUCTION TO LASERS

A-1. General Information. *a.* Lasers are finding ever increasing military applications—principally for target acquisition and fire control. These lasers are termed rangefinders, target designators and target illuminators. Lasers are also being used in communications, precision distance measurements, guidance systems, metal working, photography, holography, and medicine.

b. Laser radiation should not be confused with ionizing radiation (X-rays and gamma rays) even though laser beams with high irradiances have been known to produce ionization.

c. The word *laser* will be applied to devices using light amplification by stimulated emission of radiation and usually operating with an output wavelength of approximately 200 nm (0.2 μm) to 1000 μm (1mm). Most lasers operate in the continuous wave (CW) mode, normal pulsed mode, Q-switched mode, or mode-locked mode.

A-2. The Nature of Light. The word, light, as commonly used, refers to that portion of the electromagnetic spectrum which produces a visual effect. It was first shown by James Clerk Maxwell in 1873 that light is electromagnetic radiation which propagates at approximately 3×10^8 meters per second. Albert Einstein later predicted that the velocity of light in a vacuum is constant throughout the universe and is the ultimate speed at which energy may be transmitted. Quantum mechanics, the branch of science dealing with atomic and subatomic particles, describes the smallest indivisible quantity of radiant energy as one photon. The amount of energy Qq, represented by one photon is determined by the frequency υ, and Plank's constant, h.

$$Qq = h\upsilon \qquad (1)$$

The frequency, υ, and wavelength, λ, of light are related by the velocity of light, c, so that knowing one, the other may be determined by use of the relationship.

$$c = \upsilon\lambda \qquad (2)$$

Man has made use of almost the entire electromagnetic spectrum, from zero Hertz, such as direct current from storage batteries, to 10^{24} Hertz, the very hard X-rays used for nondestructive inspection of metal parts. Figure A-1 shows the electromagnetic frequency spectrum and some of its uses and properties.

THE ELECTROMAGNETIC SPECTRUM

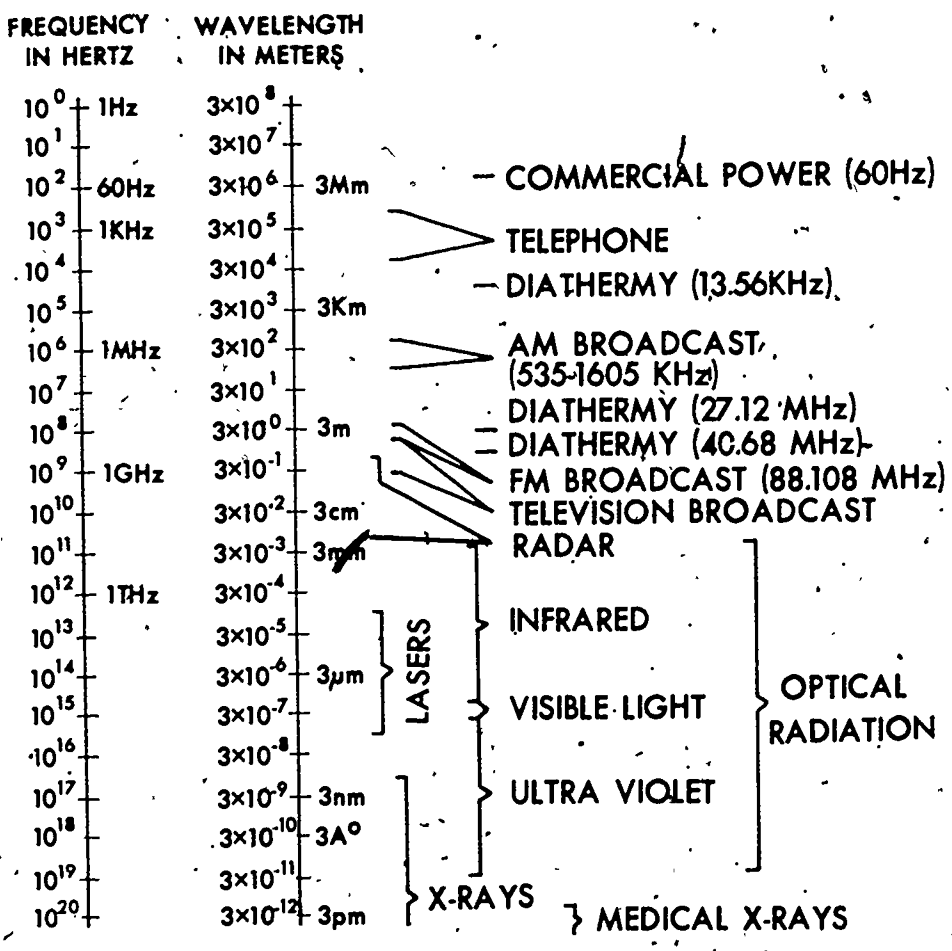


Figure A-1. The electromagnetic frequency spectrum.

A-3. Production of Light. *a.* Electromagnetic radiation is emitted whenever a charged particle, e.g., an electron, gives up energy into an electric field. This happens every time an electron drops from a higher energy state to a lower energy state in a molecule, atom, or ion (fig A-2).

b. In ordinary light sources, electron transitions from higher energy states to lower energy states occur randomly and one photon has no correlation with another. In a laser, however, these transitions are stimulated by photons of precisely the right energy. The stimulated emissions occur with exactly the same wavelength, phase, and direction as the photons that stimulated the emissions.

c. Electrons must be raised to higher energy levels before they can make the transitions to lower energy levels and radiate photons. There are many ways in which electrons can be raised to higher energy levels or become "excited":

(1) By heating, as in the filament of an incandescent lamp; by collisions with other electrons, as in a fluorescent lamp or television picture tube;

(2) By absorbing energy from photons, as in luminescent paint on a watch dial;

(3) By chemical reactions, as in a flame.

d. In addition to the familiar electronic energy levels, a molecule can also have energy levels arising from the vibrational and rotational motion of the molecules.

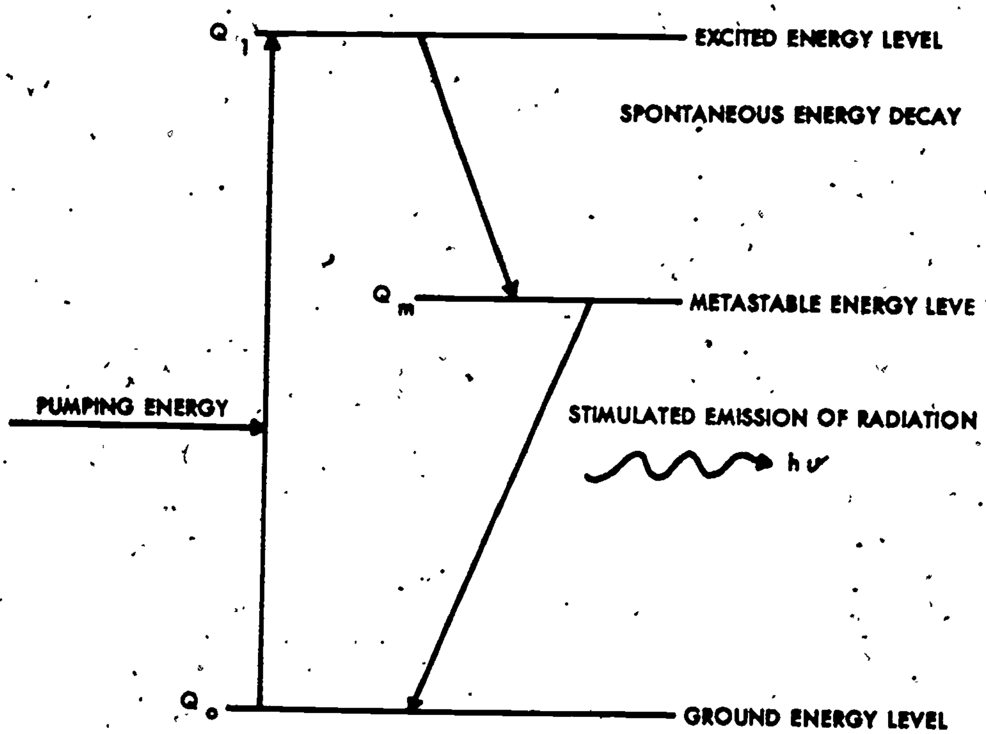


Figure A-3. Three level energy diagram, one of the many possible sets of energy levels for laser action.

A-6. Pumping System. To raise electrons to a higher energy level, lasers employ pumping systems (fig A-4). These systems pump energy into the laser material, increasing the number of electrons trapped in the metastable energy level. When the number of electrons in the metastable energy level exceeds those in the lower level, a *population inversion* exists and laser action is possible. Several different pumping systems are available—optical, electron collision, and chemical reaction:

a. Optical pumping uses a strong source of light, such as a xenon flashtube or another laser (e.g., ruby laser).

b. Electron collision pumping is accomplished by passing an electric current through the laser material or by accelerating electrons from an electron gun to impact on the laser material (e.g., Helium-Neon lasers).

c. Chemical pumping is based on energy released in the making and breaking of chemical bonds (e.g., Hydrogen-Fluoride lasers).

A-7. Optical Cavity. A resonant optical cavity is formed by placing a mirror at each end of the laser material so that a beam of light may be reflected from one mirror to the other, passing back and forth through the laser material (fig A-5). Lasers are constructed in this way so that the beam passes through the material many times and is amplified each time. One of the mirrors is only partially reflecting and permits part of the beam to be transmitted out of the cavity.

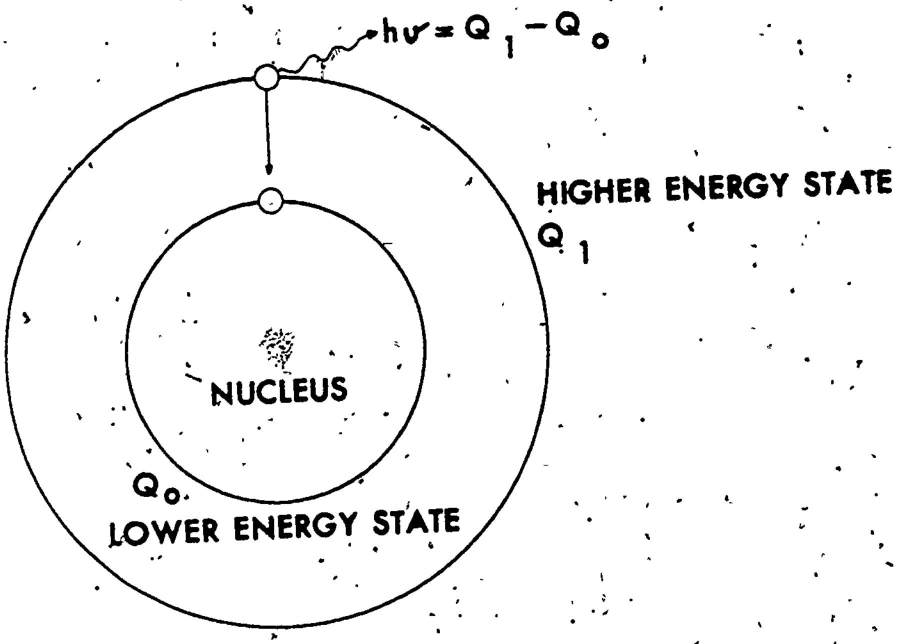


Figure A-2. Emission of radiation by transition of an electron from a higher energy state to a lower energy state.

A-4. Components of a Laser. The laser has three basic components:

a. A lasting medium

b. A pumping system (energy source)

c. A resonant optical cavity.

Lenses, mirrors, shutters and other accessories may be added to the system to obtain more power, shorter pulses, or special beam shapes but only three basic components are necessary for laser action.

A-5. Lasing Medium. A lasing medium, to have suitable energy levels, must have at least one excited state (metastable state) where electrons can be trapped and not immediately and spontaneously dropped to lower states. Electrons may remain in these metastable states from a few microseconds to several milliseconds. When the medium is exposed to the appropriate pumping energy the excited electrons are trapped in these metastable states long enough for a population inversion to occur, i.e., there are more electrons in the excited state than in the lower state to which these electrons decay when stimulated emission occurs. Figure A-3 shows a simplified three-level energy diagram for a laser material. This is just one of the many possible systems of energy levels. Although laser action is possible with only two energy levels, most such actions involve four or more levels.

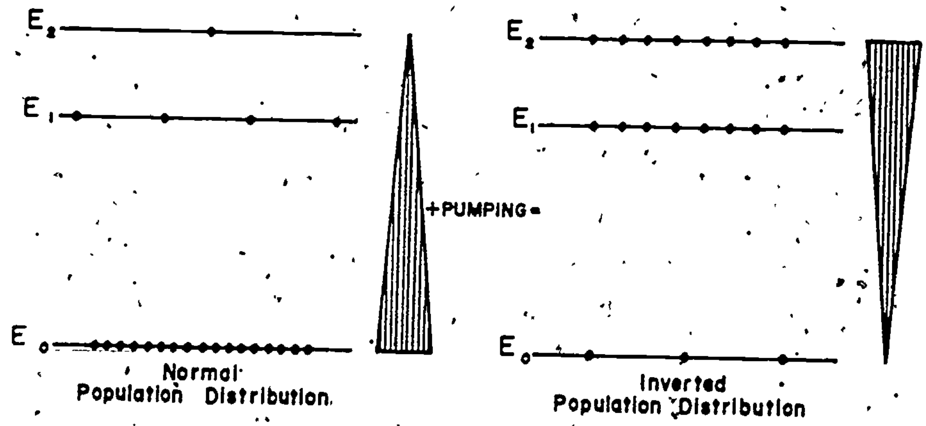


Figure A-4 Population inversion produced by pumping electrons from a lower energy state to a higher energy state so that the higher state has more electrons (larger population) than the lower state

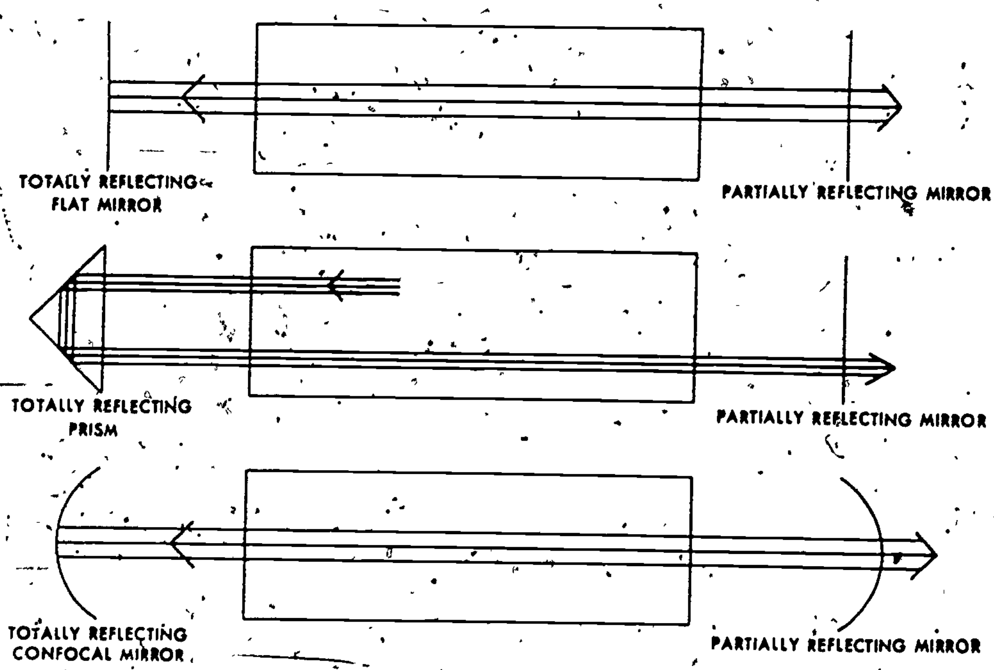


Figure A-5. Three typical optical cavities: Simple flat mirror system (top), rotating prism q-switch system (middle), and confocal mirror system (bottom).

A-8. Laser Operation. *a.* Energy is supplied to the laser material by the pumping system. This energy is stored in the form of electrons trapped in metastable energy levels. Pumping must produce a population inversion before laser action can take place.

b. A population inversion exists when a higher energy level has more electrons (population) than a lower energy level, which is contrary to natural order. A population inversion is necessary because the stimulated emission would be absorbed by lower energy level electrons.

c. When a population inversion is achieved, the spontaneous decay of a few electrons from the metastable energy level to a lower energy level starts a chain reaction. The photons emitted spontaneously will stimulate other electrons to make the transition from the metastable energy level to lower energy levels, emitting photons of precisely the same wavelength, phase, and direction.

d. When the photons reach the end of the laser material they are reflected by the end-mirror back into the material where the chain reaction continues and the number of photons is increased. When the

photons arrive at a partially reflecting mirror, only a portion will be reflected back into the cavity and the rest will emerge as a laser beam.

A-9. Types of Lasers. Lasers are often designated by the type of laser material in the optical cavity.

a. Solid state lasers employ glass or crystalline material (fig A-6): gas lasers employ pure gas or mixtures of gases (fig A-7 and A-8): semiconductor lasers employ transistor materials (fig A-9); liquid lasers employ active material in a liquid solution or suspension (fig A-10).

b. Solid state and liquid lasers commonly employ optical pumping while gas lasers usually employ electron collision pumping, although some types of liquid and gas lasers have employed chemical-reaction pumping. Semiconductor lasers may be optically pumped by another laser beam or electron-collision pumped by an electron beam or an electric current.

A-10. Modes of Operation. *a.* The different modes of operation of a laser are distinguished by the rate at which energy is delivered. In general, lasers operating in the *normal pulse* mode have pulse durations of a few tens of microseconds to a few milliseconds. This mode of operation is sometimes referred to as *long pulse* or just *pulsed.*

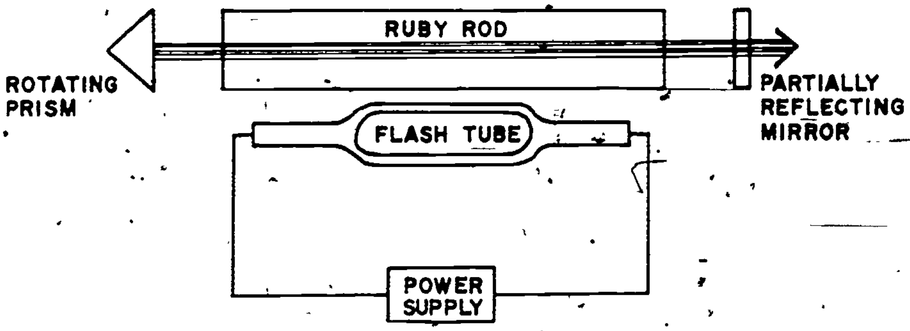


Figure A-6. Schematic of solid state laser with optical pumping

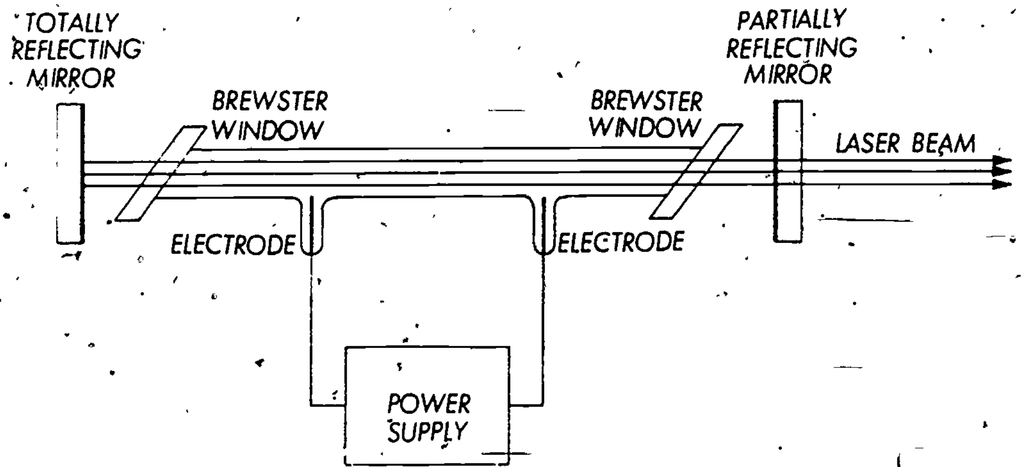


Figure A-7 Schematic of helium-neon laser with electron collision pumping, representative of small gas lasers

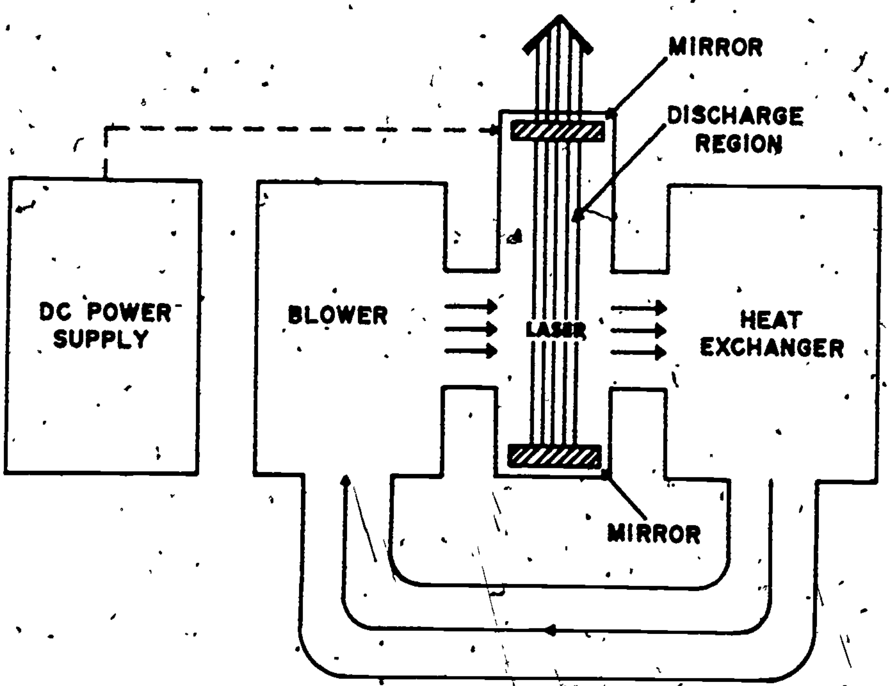


Figure A-8. Schematic of CO_2 gas transport laser (GTL) which is representative of a larger type of flowing-gas laser. A still larger type of gas laser (not shown) employs a combustion chamber and supersonic nozzles for population inversion and is known as a gas dynamic laser (GDL).

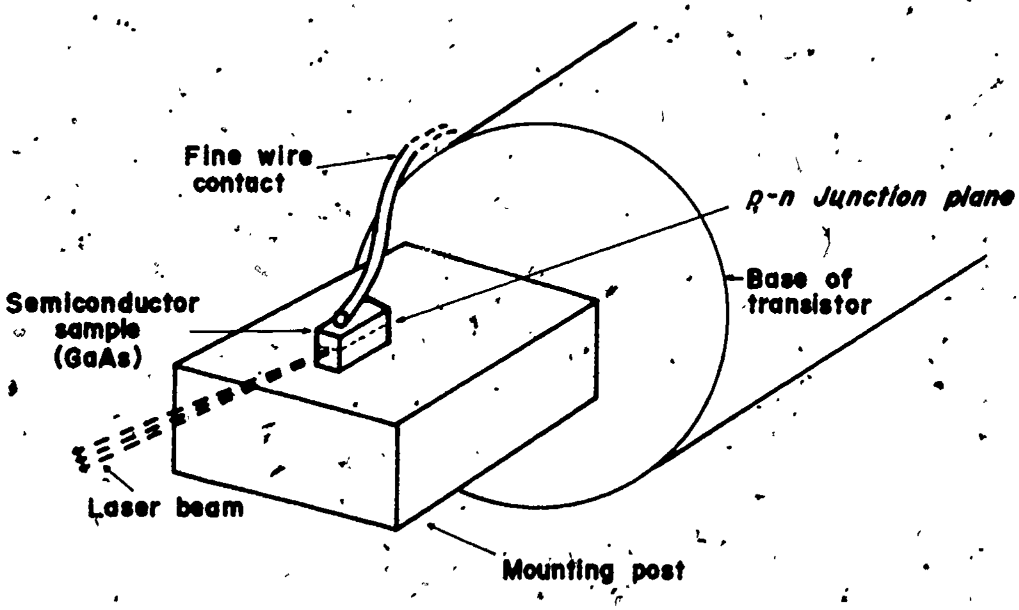


Figure A-9. Schematic of gallium-arsenide laser with direct-current (electron collision) pumping, representative of semiconductor or injection lasers.

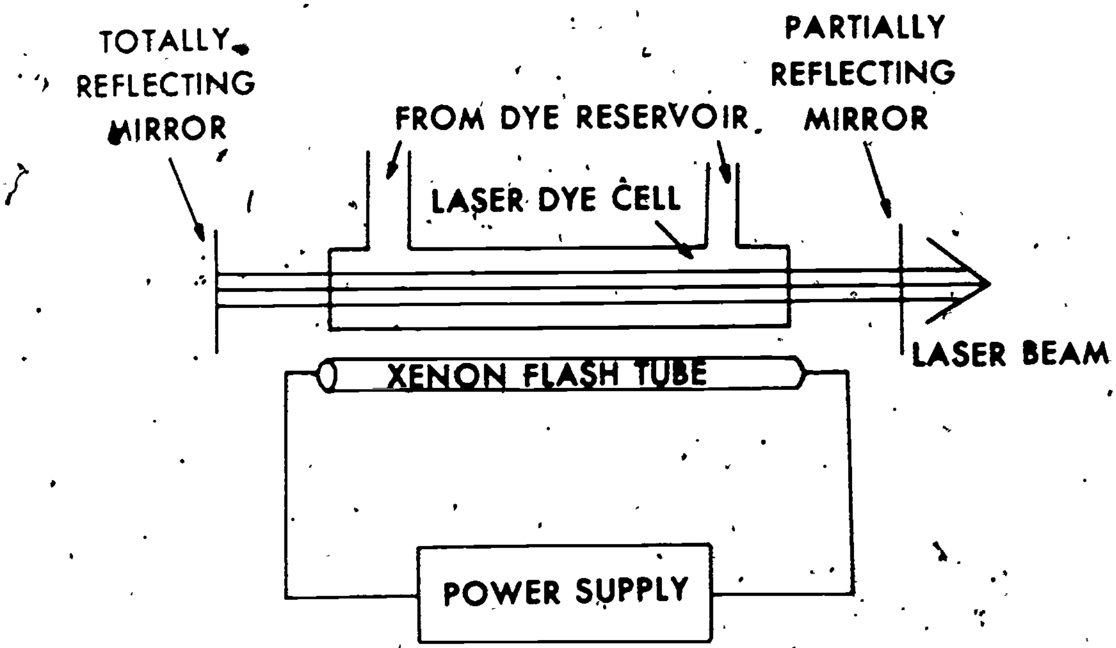


Figure A-10. Schematic of liquid dye laser with optical pumping.

b. The quality of the optical cavity of a laser can be changed by placing a shutter between the mirrors. This enables the beam to be turned on and off rapidly and normally creates pulses with a duration of a few tens of nanoseconds to a few tens of microseconds. This mode of operation is normally called *Q-switched,* although it is sometimes referred to as *Q-spoiled* or *giant pulse.* (The "Q" refers to the resonant quality of the optical cavity.) A laser operating in the Q-switched mode delivers less energy than the same laser operating in the normal pulse mode, but the energy is delivered in a much shorter time period. Thus, Q-switched lasers are capable of delivering very high peak powers of several megawatts or even gigawatts. Most military lasers are Q-switched with a pulse duration of 10 to 30 ns and are used in target acquisition and fire control.

c. When the phases of different frequency modes are synchronized, i. e., "locked together," the different modes will interfere with one another to generate a beat effect. The result will be a laser output which is observed as regularly spaced pulsations. Lasers operating in this fashion, *mode-locked,* usually produce trains of pulses, each having a duration of a few pico-seconds to a few nanoseconds. A mode-locked laser can deliver higher peak powers than the same laser operating in the Q-switched mode.

d. Some lasers are able to operate continuously. This mode of operation is called *continuous wave* or *CW.* In this mode of operation, the peak power is equal to the average power output; that is, the beam irradiance is constant with time.

e. Pulsed lasers can be operated to produce repetitive pulses. The *pulse repetition frequency* of a laser is the number of pulses which that laser produces in a given time. Lasers are now available with pulse repetition frequencies as high as several hundreds of thousands of pulses per second. There is an enormous variation in the pulse widths and pulse repetition frequencies which can be generated. Therefore, the specification of such pulse characteristics is extremely important in any evaluation of the interaction of laser radiation with biological systems.

APPENDIX B

RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS

1. PHYSICAL TERMINOLOGY

In discussing the quantitative aspects of the bioeffects of radiant energy, there are several physical terms which are often misused. There is an accepted standard nomenclature (Systeme International) of which the reader should be aware. A recent summary of radiometric and photometric terms, units, and conversion factors has been prepared by Meyer-Arendt (1968). In describing effects of radiant energy (which itself is a standard term with units of joules) upon tissue, most investigators have used power or energy per unit area (e.g., watts/cm^2 or joules /cm^2) and termed these power density or energy density. By the Systeme International, power or energy density refers to power or energy per unit volume and not per unit area. However, for the purpose of this review, these terms refer to power or energy per unit area, as widely used in the literature. Rather than radiant energy, the term "radiation" is preferable. Unfortunately, the term "radiation" means only ionizing radiation to many. One other term widely used to connote both energy density and power density is "beam intensity." By the Systeme International, "radiant intensity" is power per unit solid angle (watts per steradian) from a point source. Several other terms used in discussing ocular hazards are explained in the following two paragraphs.

The terms "luminance" and "illuminance" are "photometric" terms which are related to the visual response of the eye; whereas "radiance" and "irradiance" are "radiometric terms which are related to absolute measurements of radiation. Terms in the "photometric" system are valuable to illuminating engineers in describing levels of visible light in a given situation: whereas terms in the radiometric system are a part of the

fabric of physical units and are not dependent on the response of the eye. There are no fixed methods for translating light levels measured in one system to corresponding levels in the other system, since such factors would depend upon the spectral distribution of the radiant source, i.e., how much of the source energy is infrared and ultraviolet radiation not visible to the eye, and how much is in the spectral band to which the eye is most sensitive.

The terms "radiance" and "luminance" are used to describe the rate of light or radiant energy leaving the source per solid angle, i.e., the "brightness" of the source. Alternatively, the terms "irradiance" and "illuminance" are used to describe the level arriving at a given point in space; i.e., the level measured by detector which measures the number of photons falling upon a unit area of surface. Table I provides a list of these terms and their units.

Table 1

USEFUL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS[1,2]

RADIOMETRIC				PHOTOMETRIC			
Term	Symbol	Defining Equation	SI Unit and Abbreviation	Term	Symbol	Defining Equation	SI Units and Abbreviation
Radiant Energy	Q_e		Joule (J)	Quantity of Light	Q_v	$Q_v = \int \Phi_v dt$	lumen-second (lm·s) (talbot)
Radiant Energy Density	W_e	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter ($J \cdot m^{-3}$)	Luminous Energy Density	W_v	$W_v = \frac{dQ_v}{dV}$	talbot per square meter ($lm \cdot s \cdot m^{-3}$)
Radiant Power (Radiant Flux)	Φ_e, P	$\Phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux	Φ_v	$\Phi_v = 680 \int \frac{d\Phi_e}{d\lambda} V(\lambda)\, d\lambda$	lumen (lm)
Radiant Exitance	M_e	$M_e = \frac{d\Phi_e}{dA} = \int L_e \cdot \cos\theta \cdot d\Omega$	Watt per square meter ($W \cdot m^{-2}$)	Luminous Exitance	M_v	$M_v = \frac{d\Phi_v}{dA} = \int L_v \cdot \cos\theta \cdot d\Omega$	lumen per square meter $lm \cdot m^{-2}$
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	E_e	$E_e = \frac{d\Phi_e}{dA}$	Watt per square meter ($W \cdot m^{-2}$)	Illuminance (luminous flux density)	E_v	$E_v = \frac{d\Phi_v}{dA}$	lumen per square meter ($lm \cdot m^{-2}$) lux (lx)
Radiant Intensity	I_e	$I_e = \frac{d\Phi_e}{d\Omega}$	Watt per steradian ($W \cdot sr^{-1}$)	Luminous Intensity (candlepower)	I_v	$I_v = \frac{d\Phi_v}{d\Gamma}$	lumen per steradian (lm·sr) or candela (cd)
Radiance	L_e	$L_e = \frac{d^2\Phi_e}{d\Omega \cdot dA \cdot \cos\theta}$ [5]	Watt per steradian and per square meter ($W \cdot sr^{-1} \cdot m^{-2}$)	Luminance	L_v	$L_v = \frac{d^2\Phi_e}{d\Gamma \cdot dA \cdot \cos\theta}$ [5]	candela per square meter ($cd \cdot m^{-1}$)
Radiant Exposure (Dose in Photobiology)	H_e	$H_e = \frac{dQ_e}{dA}$	Joule per square meter ($J \cdot m^{-2}$)	Light Exposure	H_v	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx·s)
				Luminous Efficacy (of radiation)	K	$K = \frac{\Phi_v}{\Phi_e}$	lumen per watt ($lm \cdot W^{-1}$)
				Luminous Efficiency (of a broad band radiation)	V(*)	$V(*) = \frac{K}{K_m} = \frac{K}{680}$	unitless
Radiant Efficiency[3] (of a source)	η_e	$\eta_e = \frac{P}{P_i}$	unitless	Luminous Efficacy[3] (of a source)	η_v	$\eta_v = \frac{\Phi_v}{P_i}$	lumen per watt ($lm \cdot W^{-1}$)
Optical Density[4]	D_e	$D_e = -\log_{10} \tau_e$	unitless	Optical Density[4]	D_v	$D_v = -\log_{10} \tau_v$	unitless
				Retinal Illuminance in Trolands	E_t	$E_t = \frac{L_v}{S_p}$	troland (td) = luminance in $cd \cdot m^{-2}$ times pupil area in mm^2

1. The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript λ. For example, spectral irradiance H_λ has units of $W \cdot m^{-2} \cdot m^{-1}$ or more often, $W \cdot cm^{-2} \cdot nm^{-1}$.
2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or μm are most commonly used to express wavelength.
3. P_i is electrical input power in watts.
4. τ is the transmission.
5. At the source $I = \frac{dI}{dA \cdot \cos\theta}$ and at a receptor $I = \frac{dE}{d\Omega}$

1. METRIC SYSTEM/EQUIVALENT UNITS.

Length.

1 m = 100 cm = 1,000 mm = 39.37 inches

1 cm = 0.3938 inches; 1 inch = 2.54 cm

1 μm = 10^{-6} meters = 10^{-4} cm

Time.

1 msec = 1/1,000 second = 1×10^{-3} second

1 μsec = 1/1,000,000 second = 1×10^{-6} second

1 nsec = 1×10^{-9} second

Angle. 1 milliradian = 10^{-3} radian = .057 degree = 3.4 arc-minutes = 1 mil

Solid Angle. 1 sr = one steradian = 1/4π sr in one sphere

1 hertz - 1 cycle/second

1 kilohertz = 1,000 hertz = 1×10^3 hertz

1 megahertz = 1,000,000 hertz = 1×10^6 hertz

1 gigahertz - 1,000,000,000 hertz = 10^9 hertz

EXPONENTIAL SYSTEM. For convenience in writing and manipulation, unwieldly numbers are written as factors of appropriate powers of 10. The following examples will illustrate:

2,380,000,000 = 2.38×10^9

2.38 = 2.38×10^2

0.238 = 2.38×10^{-1}

0.000000238 = 2.38×10^{-7}

CHAPTER 1

GENERAL

1-1. Purpose. This regulation establishes Department of the Army policies, procedures, and standards for the protection of personnel from the hazards to health of optical radiation. It outlines procedures to be followed in the event of a known or suspected overexposure of personnel to such radiation.

1-2. Scope. This regulation is applicable to all commands of the Department of the Army.

1-3. Definitions. *a. Optical radiation.* Electromagnetic radiation within the wavelength range 100 nanometers to 1 millimeter (10^6 nanometers) (i.e., ultraviolet, visible, and infrared radiation).

b. Laser. An acronym for Light Amplification by Stimulated Emission of Radiation. As used in this regulation, laser denotes either the laser radiation source itself, or an entire system embodying such a source, as appropriate.

c. Optical source. Any source of optical radiation, e.g. searchlights, lasers, and electric arcs.

d. Laser protection standards. Published standards for laser exposure which will insure that personnel will not sustain injury in the light of existing medical knowledge.

e. Ocular hazard distance. The distance of the human eye from the operating laser or other optical source within which the beam radiant exposure or irradiance exceeds the applicable optical radiation protection standard.

f. Units. Radiometric units used shall be in accordance with the International System of Units adopted by the 11th General Conference on Weights and Measures, October 1960 and the International Lighting Vocabulary Publication CIE No. 17 (E-1.1) 1970, published by the International Commission on Illumination.

1-4. Policy. *a.* Exposure to laser radiation shall be controlled to insure that individuals are not subjected to levels in excess of those established by the Protection Standards prescribed in chapter 2.

b. Laser hazard assessments will be accomplished in accordance with provisions of TB MED 279.

c. Medical surveillance programs will be established to insure that appropriate physical examinations are accomplished on those individuals employed to work in a potentially hazardous laser radiation area.

d. Lasers and other optical sources will be operated in such a way as to avoid potentially hazardous exposure of personnel who may be in the vicinity of the optical beam and within the ocular hazard distance as determined by the US Army Environmental Hygiene Agency (USAEHA).

1-5. Responsibility. Responsibility for control of potential hazards to personnel from lasers and other optical equipment.

a. The Surgeon General, Department of the Army, is responsible for the evaluation of potential optical radiation hazards to personnel operating lasers, searchlights, and similar equipment which generate optical radiation, that are utilized by the Department of the Army.

(1) The Surgeon General, pursuant to AR 10-5, will evaluate for development and design agencies the potential health hazards of equipment utilizing lasers and other optical source systems and provide guidance on measures which may be taken to avoid or prevent excessive exposure of personnel to optical radiation. These evaluations will be conducted by USAEHA.

(2) The Surgeon General will evaluate plans upon request for the installation of laser equipment and make studies of the environmental conditions at user sites or test facilities.

(3) USAEHA will conduct periodic comprehensive surveys of laser installations at least every 3 years. These surveys will include evaluation of characteristics of laser equipment and activities at the site which may result in exposure of personnel, determination of the effectiveness of interlocks, eye protection, warning and/or limiting devices and review of standing operating procedures and other controls related to personnel protection.

b. Agencies responsible for the development and design of laser equipment or its incorporation into weapons control or communications systems will insure that such equipment is evaluated for personnel exposure potential during the design,

development, and testing of the equipment. The Surgeon General will be notified in sufficient time to provide the services noted in paragraph *a* above. Pertinent information derived from this evaluation will be made available on request to any major Army commanders who have installations or activities within their command which operate such equipment.

c. Major Army commanders who have installations and activities under their command which operate laser and high intensity light source equipment are responsible for—

(1) Disseminating to installations and activities operating such equipment under their command information relating to the measures required for the control of exposure of personnel.

(2) Assuring that installations and activities operating such equipment under their command have in force adequate programs as specified in *d* below for the control of exposure of personnel.

(3) Prescribing conditions under which interlocks, eye protection filters, and limiting and/or warning devices installed on equipment may be by-passed or overridden during combat alerts, training exercises, or in maintenance or calibration of equipment.

d. Installation and activity commanders responsible for the operation or testing of potentially hazardous optical equipment will take necessary measures to assure that—

(1) Personnel working in the vicinity of laser equipment and high intensity optical sources are informed as to the potential personnel health hazards associated with exposure to optical radiation from the specific equipment being used.

(2) Standing operating procedures are published and enforced, as required, concerning such matters as the control of the positioning of optical devices, control of the movement of personnel, and the minimization of exposure of personnel in the vicinity of the hazardous optical beam(s).

(3) Protective devices are labeled and used only under the conditions for which they are designed.

(4) Appropriate areas of possible hazardous exposure are placarded to indicate the nature of the hazard. The placard will be in accordance with AR 385-30.

(5) Any suspected laser radiation accidents involving individual exposure in excess of protection standards are reported in accordance with AR 385-40. The report should include—

(*a*) A description of the laser installation and circumstances leading to the exposure.

(*b*) Details of the immediate and subsequent ophthalmologic findings.

(6) All personnel who are employed to work in a potentially hazardous laser area (paragraph 1-6*a*) are included in an occupational vision program which encompasses thorough general ophthalmologic examinations before being assigned to work with laser-producing equipment, 1 to 2-year intervals thereafter, and on termination of such employment.

1-6. Medical surveillance.

a. Personnel to be examined. An individual whose occupation or assignment may result in a significant risk of exposure to potentially hazardous levels of optical radiation shall have a preplacement medical examination, a termination of employment examination, and be included in an occupational vision program. The following types of individuals are considered in this category.

(1) Those individuals routinely using lasers in any RDTE effort.

(2) Certain laser equipment, such as tripod-mounted, hand-held or airborne laser rangefinders, designators, or illuminators may be determined to present a sufficient hazard to operators and maintenance personnel that such personnel may be required by The Surgeon General to be examined. The warning page of the technical manual for each laser device will indicate which types of user or maintenance personnel should be examined

(3) Maintenance personnel routinely working with laser rangefinders, illuminators, or designators.

(4) Operators and maintenance personnel routinely working with engineering laser transits, geodimeters, and alignment devices which have a radiant power output exceeding 1 milliwatt.

b. Examination requirements. The medical examination shall follow the procedures in TB MED 279.

c. Examination of personnel known or suspected to have been injured by lasers. Personnel who are known or suspected to have been accidentally exposed to levels in excess of applicable laser protection standards shall be examined as soon as possible following such exposure. Personnel

working with lasers or other high intensity optical sources who complain of persistent after-images or other visual disturbances should be examined.

1-7. Requests for assistance. Requests for technical assistance from USAEHA in evaluating hazards from lasers and other high intensity optical sources should be directed through appropriate command channels per AR 40-4 to HQDA (DASG-HCH), WASH DC 20314.

Extracts From TB Med 279, 18 Sep 74

1. Introduction. *a.* The term LASER is an acronym derived from Light Amplification by Stimulated Emission of Radiation The effects of laser radiation are essentially the same as optical radiation generated by more conventional ultraviolet, infrared, and visible optical sources The unique biological implications attributed to laser radiation are generally those resulting from the very high beam collimation, beam intensities and monochromaticity of many lasers. Such sources differ from conventional sources of optical radiation primarily in their ability to attain highly coherent radiation (in phase). The increased directional intensity of the optical radiation generated by a laser results in concentrated optical beam irradiances at considerable distances A short summary of types of lasers and their characteristics is provided in appendix A.

b. Recent developments in laser technology have resulted in an increase in the utilization of these devices for military applications, both for research and field use. Field military lasers are used principally for target acquisition and fire control. The widespread use of these systems increases the probability of personnel exposure to injurious levels of laser radiation. Although these effects can be used to good advantage, they are potentially hazardous and adequate safeguards must be provided.

c. The evaluation of laser hazards can be highly technical. However, in the interest of simplifying the task of developing range controls in the field, this bulletin is organized with practical guidance for this requirement in paragraph 10 More specialized information may be found in paragraphs 7, 8 and 9. Detailed technical information for highly specialized laser applications may be found in appendixes B, C and D.

2. Purpose and Scope. This bulletin provides guidelines for personnel protection within the framework of currently documented experimental evidence. The medical guidance possible is limited by the biologic data available. The scope of this bulletin encompasses the portion of the electromagnetic spectrum which includes ultraviolet, visible light, and infrared in which laser radiation can be produced.

3. Definitions. *a. Accommodation*—The ability of the eye to change its power and thus focus for different object distances.

b. Angstrom (Å)—A unit of measure of wavelength equal to 10^{-10} meter, 0.1 nanometer, or 10^{-4} micrometer.

c. Attenuation—The decrease in the radiant flux of any optical beam as it passes through an absorbing and/or scattering medium.

d. Beam Diameter (D_L)—The distance between diametrically opposed points in the cross-section of a circular beam where the power per unit area is 1/e times (37%) that at the peak.

e. Beam Divergence (Φ)—Angle of beam spread measured in radians or milliradians (1 milliradian = 3.4 minutes of arc or approximately 1 mil) For small angles where the chord is approximately equal to the arc, the increase in the diameter of the beam is numerically equal to 1,000th of the range in meters multiplied by the number of milliradians of beam divergence. That is, at 1,000 meters range a beam divergence of 2 milliradians would give beam diameter 2 meters wider than the emergent beam diameter.

f Beam Splitter—An optical device using controlled reflection to produce two beams from a single incident beam

g Closed Installation—Any location where lasers are used which will be closed to unprotected personnel during laser operation.

h CW Laser—Continuous wave laser, as distinguished from a pulsed laser A laser emitting for a period in excess of 0.25 second.

i. Controlled Area—An area where the occupancy and activity of those within are subject to control and supervision for the purpose of protection from optical radiation hazards.

j. Diffuse Reflection—Takes place when different arts of a beam incident on a surface are reflected over a wide range of angles.

k. Duty-Cycle—Ratio of "on time" to total exposure duration for a repetitively pulsed laser

l. Electromagnetic Radiation—The propagation of varying electric and magnetic fields through space at the velocity of light

m. Emergent Beam Diameter (a)—Diameter of the laser beam at the exit aperture of the system in centimeters (cm).

n. Inclosed Laser System—Any laser or laser system located within an inclosure which does not permit emission of hazardous optical radiation from the inclosure.

o. Energy (Q)—The capacity for doing work. Energy content is commonly used to characterize the output from pulsed lasers, and is generally measured in joules (J).

p. Exempt Power (Φ-exempt) *and Exempt Energy* (Q-exempt)—P exempt is that output power (Q exempt that output energy/pulse) of a laser under consideration such that no applicable protection standard for exposure of the eye for a specified exposure duration can be exceeded under any possible viewing conditions with or without optical instruments, whether or not the beam is focused, (app C).

q. Extended Source—An extended source of radiation can be resolved into a geometrical image in contrast with a point source of radiation, which

cannot be resolved into a geometrical image. For the purposes of this bulletin, a source which subtends an angle greater than α min (Symbols, app D).

r Gas Laser—A type of laser in which the laser action takes place in a gas medium, usually operated as a CW laser.

s. Hertz (Hz)—Unit of frequency, i.e. "cycles per second."

t. Infrared Radiation (IR)—Electromagnetic radiation with wavelengths which lie within the range of 0.7 to 1000 μm. This region is often broken into three spectral bands by wavelength IR A (0.7-0.78 to 1.4 μm), IR-B (1.4 μm to 3 μm), and IR-C (3 μm to 1 mm).

u Integrated Radiance (L_p)—Product of the exposure duration times the radiance. Also known as pulsed radiance ($W \cdot s \cdot cm^{-2} sr^{-1} = J \cdot cm^{-2} \cdot sr^{-1}$).

v Intrabeam Viewing—Viewing the laser source from within the beam. The beam may either be direct or specularly reflected.

w Irradiance (E)—Radiant flux density on a given surface, in units of watts-per-square-centimeter ($W \cdot cm^{-2}$).

x Joule (J)—A unit of energy (1 watt-second) used normally in describing a single pulsed output of a laser, it is equal to one watt-second or 0.239 calories.

y Joule•cm^{-2} ($J \cdot cm^{-2}$)—A unit of radiant exposure used in measuring the amount of energy per unit area of absorbing surface or per unit area of a laser beam.

z Lambertian Surface—An ideal diffuse surface whose emitted or reflected radiance (brightness) is independent of the viewing angle.

aa Laser—A source of intense, coherent and directional optical radiation. Also, an acronym for: *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation. A laser usually is composed of an energy source, a resonant cavity, and an active lasing medium.

ab Laser Device—Either a *laser* or a *laser system.*

ac. Laser System—An assembly of electrical, mechanical, and optical components which includes a laser.

ad Laser Controlled Area—Any area which contains one or more lasers and in which the activity of personnel is subject to control and supervision.

ae. Light—Visible radiation (400 nm to 700-780 nm). For the purposes of this bulletin, limited to wavelengths between 400 and 700 nm.

af Micrometer (μm)—Formerly termed "micron", a measure of length equal to 10^{-6} m or 1000 nanometers.

ag. Nanometer (nm)—Unit of length equal to 10^{-9} m or 0.001 μm.

ah. Open Installation—Any location where lasers are used which will be open to operating personnel during laser operation and may or may not specifically restrict entry to casuals.

ai. Optical Density (D_λ)—A logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter.

Optical density $D_\lambda = \log_{10} [\Phi_0/\Phi_t]$
Where Φ_0 is the incident power and Φ_t is the transmitted power at a specific wavelength λ.

aj. Optically Pumped Lasers—A type of laser that derives energy from another light source such as a xenon flash lamp (coherent light sources have also been used).

ak. Output Power and Output Energy—The laser output power is used primarily to rate CW lasers since the energy delivered per unit time remains relatively constant (output measured in watts). In contrast, pulsed lasers deliver energy in pulses and their effects may best be categorized by energy output per pulse. [The power output level of CW lasers is usually expressed in milliwatts (mW = 1/1000 watt) or watts, pulsed lasers in the kilowatt range (kW = 1000 watts), and q-switched pulsed lasers in the megawatt (MW = million watts) or gigawatt range (GW = billion watts)]. Pulsed energy output is usually expressed in joules or millijoules (mJ = 1/1000) per pulse.

al Point Source of Optical Radiation—Ideally, a source with infinitesimal dimensions. Practically, a source of radiation whose dimensions are small compared with the viewing distance. For this guide, a source which subtends an angle at the viewer less than *a*.

am. Power (Φ)—The time rate at which energy is transferred. Usually expressed in watts (joules-per-second).

an. PRF—Abbreviation for pulse repetition frequency.

ao. Pulse Duration—Duration of a pulsed laser flash, it may be measured in terms of milliseconds (ms = 10^{-3} s), microseconds (μsec = 10^{-6} s), or nanoseconds (ns = 10^{-9} s). The time interval between the half-peak-power points on the leading and trailing edges of the pulse.

ap. Pulsed Laser—A laser that delivers its energy in short pulses, as distinct from a CW laser. For the purpose of this bulletin a laser which emits for less than 0.25s.

aq. Q-Switched Laser—Also known as *Q-spoiled*—is a laser capable of extremely high peak powers for very short durations (pulse duration of several nanoseconds).

ar. Radian—A unit of angular measure equal to the angle subtended at the center of a circle by a chord whose length is equal to the radius of the circle.

One (1) Radian = 57.3 Degrees
Or 2 π Radians = 360 Degrees

as. Radiance (L)—Radiant flux (radiant power) output per unit solid angle per unit area ($W \cdot sr^{-1} \cdot cm^{-2}$); radiometric brightness.

at. Radiant Energy (Q)—Energy in the form of electromagnetic waves usually expressed in units of joules (watt-seconds).

au. Radiant Exposure (H) — The total energy per unit area incident upon a given surface in a given time interval. It is used to express exposure dose to pulsed laser radiation and is commonly expressed in $J \cdot cm^{-2}$.

av. Radiant Flux or *Radiant Power* (Φ)— The time rate of flow of radiant energy. Units — watts. (one (1) watt = 1 joule-per-second)

aw. Radiant Intensity (I) — Radiant power in a given direction—radiant flux emitted from the source per unit solid angle (steradian), in the direction of propagation, usually expressed in $W \cdot sr^{-1}$.

ax. Reflectance or Reflectivity (ρ) — The ratio of reflected radiant flux to incident radiant flux.

ay. Repetitively Pulsed Laser—A pulsed laser with reoccurring pulsed output. The frequency of the pulses is termed pulse repetition frequency (PRF). Repetitively pulsed lasers have properties similar to CW lasers if the PRF or duty cycle is very high.

az. Scintillation—In laser work, this term is frequently used to describe the effect upon a laser beam by atmospheric turbulence.

ba. Semiconductor or Injection Diode Laser— A class of lasers which at present produce relatively low average power outputs.

bb. Solid Angle (Ω) — The ratio of the area on the surface of a sphere to the square of the radius of that sphere. It is expressed in steradians (sr).

bc. Specular or Regular Reflection— A mirror-like reflection.

bd. Steradian (sr) — The unit of measure for a solid angle. There are 4 π steradians in a sphere.

be. Transmittance or transmissivity (τ) — the ratio of total transmitted radiant power to total incident radiant power.

bf. Ultraviolet radiation— Electromagnetic radiation with wavelengths between soft X-rays and visible, violet light. This region is often broken down into three spectral bands by wavelength: UV-A (315-400 nm), UV-B (280-315 nm, and UV-C (200-280 nm).

bg. Visible Radiation (Light) — Electromagnetic radiation which can be detected by the human eye. It is commonly used to describe wavelengths which lie in the range between 400 nm and 700-780 nm. For the purposes of this bulletin, it is limited to wavelengths between 400 and 700 nm.

bh. Watt (W) — The unit of power or radiant flux, one Joule-per-second. Used principally with CW lasers.

bi. Watt/cm² ($W \cdot cm^{-2}$) — A unit of irradiance used in measuring the amount of power-per-area of absorbing surface, or per area of a CW laser beam.

bj. Wavelength (λ)—The distance between two points in a periodic wave which have the same phase is termed one wavelength. The velocity of light (3×10^{10} $cm \cdot sec^{-1}$) divided by frequency (in Hz) equals wavelength (in cm).

4. Biologic Effects. *a. General* Laser radiation should not be confused with ionizing radiation (such as X and gamma rays) although very high irradiances have been known to produce ionization in air and other materials. The biologic effects of laser radiation are essentially those of visible, ultraviolet or infrared radiation upon tissues However, radiant intensities typically produced by lasers are of magnitudes that could previously be approached only by the sun, nuclear weapons, burning magnesium, or arc lights. This is one of the important properties that make lasers potentially hazardous. Laser radiation incident upon biologic tissue will be reflected, transmitted, and/or absorbed. The degree to which each of these effects occurs depends upon various properties of the tissue involved. Absorption is selective, as in the case of visible light, darker material such as melanin or other pigmented tissue absorbs more energy

b. Skin. Adverse thermal effects resulting from exposure of the skin to radiation from 315 nm to 1 mm may vary from mild reddening (erythema) to blistering and charring, depending upon the exposure dose rate and the dose (amount of energy) transferred and conduction of heat away from the absorption site. Adverse skin effects resulting from exposure to actinic ultraviolet radiation (200-315 nm) vary from erythema to blistering depending upon the wavelength and total exposure dose

c. Eye.

(1) General. In almost all situations the eye is the organ most vulnerable to injury Figure 1 provides a schematic representation of absorption of electromagnetic radiation by the eye:

(a) Most higher energy X rays and gamma rays pass completely through the eye, with relatively little absorption.

(b) Absorption of short-ultraviolet (UV-B and UV-C) and far-infrared (IR-B and IR-C) radiation occurs principally at the cornea.

(c) Near ultraviolet (UV-A) radiation is primarily absorbed in the lens.

(d) Light is refracted at the cornea and lens and absorbed at the retina; near-infrared (IR-A) radiation is also refracted and is absorbed in the ocular media and at the retina.

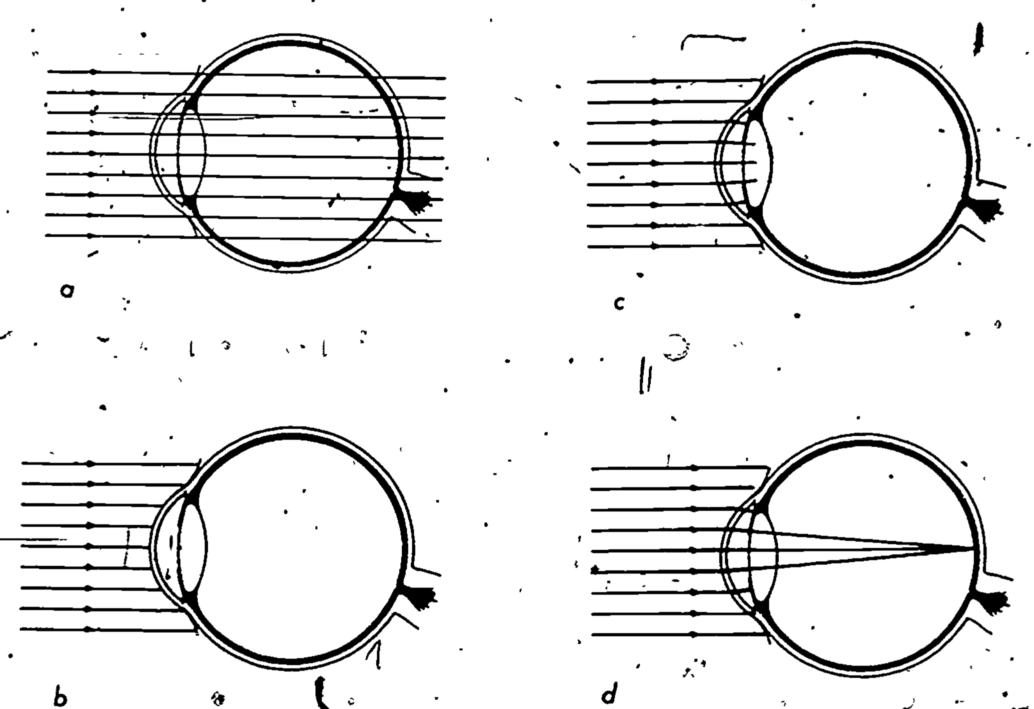


Figure 4. Absorption of electromagnetic radiation by the eye.

(2) Light (400-700 nm) and Near-Infrared (IR-A) Radiation (700-1400 nm). Adverse laser effects are generally believed to be limited largely to the retina in this spectral region. The effect upon the retina may be a temporary reaction without residual pathologic changes, or it may be more severe with permanent pathologic changes resulting in a permanent scotoma. The mildest observable reaction may be simple reddening: as the retinal irradiance is increased, lesions may occur which progress in severity from edema to charring, with hemorrhage and additional tissue reaction around the lesion. Very high radiant exposures will cause gases to form near the site of absorption which may disrupt the retina and may alter the physical structure of the eye. Portions of the eye other than the retina may be selectively injured, depending upon the region where the greatest absorption of the specific wavelength of the laser energy occurs and the relative sensitivity of tissue affected.

(3) Ultraviolet Radiation (200-400 nm). Actinic ultraviolet radiation UV-B and UV-C (200-315 nm), can produce symptoms similar to those observed in arc welders. It may cause severe acute inflammation of the eye and conjunctiva. UV-B and UV-C radiation does not reach the retina. Near ultraviolet radiation (UV-A) is absorbed principally in the lens which causes the lens to fluoresce. Very high doses can cause corneal and lenticular opacities. Insignificant levels of UV-A reach the retina.

(4) Far-Infrared Radiation, IR-B and IR-C, (1.4-1000 μm). Absorption of far-infrared radiation produces heat with its characteristic effect on the cornea and the lens of the eye. The 10.6 micrometer wavelength from the carbon-dioxide laser is absorbed by the cornea and conjunctiva and may cause severe pain and destructive effects.

5. Medical Surveillance. *a. Personnel to be Examined.* In accordance with AR 40-46 an individual whose occupation or assignment may result in a significant risk of exposure to potentially hazardous levels of optical radiation shall have a preplacement medical examination, a termination of employment examination, and other examinations as appropriate. The following types of individuals are considered in this category:

(1) Those individuals *routinely* using medium power or high power (app C) lasers in any RDTE effort, where absolute protective measures are not feasible.

(2) Certain laser equipment, such as tripod-mounted, hand-held or airborne laser rangefinders, designators, or illuminators may be determined to present a sufficient hazard to operators and related personnel that such personnel may be required by The Surgeon General to be examined. The warning page of the technical manual for each laser device will indicate which types of user or related personnel should be examined.

(3) Maintenance personnel *routinely* working with laser rangefinders, illuminators, and designators.

(4) Operators and maintenance personnel *routinely* working with medium power (app C) engineering laser transits, geodimeters, and alinement devices.

b. Examination Requirements The medical examination shall be performed by an ophthalomologist, and shall include –

(1) Recording visual acuity with correction (if below 20/40, check for improvement with pin hole or ± 0.50D spheres and 0 25D X-cyl)

(2) Dilating pupil and examining fundus carefully.

(3) Photographing or carefully describing or drawing any lesions seen.

(4) Performing slit lamp examination if the individual is potentially exposed to infrared or ultraviolet laser radiation.

6. **Protection Standards.** A complete listing of protection standards for the maximum permissible exposure of the eye and skin as specified in AR 40-46 are provided in appendix A. Protection standards commonly required for the evaluation of lasers used in military applications are given in table 1.

Table 1. Protection Standards for Typical LASERS

Type of Laser	PRF	Wavelength	Exposure Duration	Protection standard for intrabeam viewing by the eye
Single Pulse Ruby Laser Rangefinder	Single Pulse	694 3 nm	1 ns-18 μs	5 X 10^{-7} J cm $^{-2}$ /pulse
Repetitively Pulsed Ruby Laser Rangefinders and Designators	10 Hz	694 3 nm	1 ns-18 μs	1.6 X 10^{-7} J cm $^{-2}$ /pulse
	20 Hz			1 1 X 10^{-7} J cm $^{-2}$ /pulse
Single-Pulse Neodymium Rangefinder	Single Pulse	1060 nm	1 ns-100 μs	5 X 10^{-6} J cm $^{-2}$ /pulse
Repetitively Pulsed Neodymium Rangefinders and Designators	10 Hz	1060 nm	1 ns-100 μs	1 6 X 10^{-6} J·cm $^{-2}$ /pulse
	20 Hz	1060 nm	1 ns-100 μs	1.1 X 10^{-6} J·cm $^{-2}$ /pulse
CW Argon Lasers	CW	488 nm & 514.5 nm	0 25 s	2 5 mW·cm $^{-2}$
CW Argon Lasers	CW	488 nm & 514 5 nm	4 to 8 hrs	1 μW cm $^{-2}$
CW Helium-Neon Lasers (for Alinement, etc)	CW	632 8 nm	0.25 s	2 5 mW cm $^{-2}$
			4 to 8 hrs	1 μW.CM $^{-2}$
CW Neodymium YAG Laser	CW	1064 nm	100 s-8 hrs	0.5 mW.cm $^{-2}$
Erbium Laser Rangefinder or Designator	Single Pulse	1540 nm	1 ns-1 μs	1 J·cm $^{-2}$ /pulse
Holmium Laser Rangefinder	Single Pulse	2010 nm	1 ns-100 ns	10^{-2} J.cm $^{-2}$ /pulse
CW Carbon-Dioxide Laser	CW	10 6 μm	10 s-8 hrs	0.1 W.cm $^{-2}$
CW Carbon-Monoxide Laser	CW	4 7 μm	10 s-8 hrs	0.1 W cm $^{-2}$

7. **Hazard Evaluation.** *a General Procedure* Three aspects of a laser application influence the total hazard evaluation and thereby influence the application of control measures

(1) The laser device's capability of injuring personnel.

(2) The environment in which the laser is used

(3) The personnel who may be exposed.

A practical means for both evaluation and control of laser radiation hazards is to first classify laser devices according to their relative hazards and then to specify approximate controls for each classification. The use of the classification method will in most cases preclude any requirement for laser measurements and greatly reduce the need for calculations. This standardized laser classification scheme defines aspect 1 – the potential hazard of the laser device. Aspects 2 and 3 vary with each laser application and cannot be readily included in a general classification scheme. The total hazard evaluation procedure must consider all three aspects, although in most cases only aspect 1 influences the control measures which are applicable.

b. Laser and Laser System Hazard Classification Scheme.

(1) The five hazard classifications are defined by the laser output parameters and are specified in detail in appendix C. The general classification scheme with general hazard control concepts is as follows:

(a) Class I – Exempt (EL) laser devices are those not capable of emitting hazardous laser radiation under any operating or viewing condition.

(b) Class II – Low power (LP) laser devices are those CW visible (400-700nm) laser devices having a total power between 0.4 μW and 1 mW. Precautions are required only to prevent continuous staring into the direct beam, momentary (< 0.25 sec) exposure as would occur in an unintentional viewing situation is not considered hazardous.

(c) Class III—Medium power (MP) laser devices are potentially hazardous if the direct beam is viewed by the unprotected eye, but do not (unless focused) cause hazardous diffuse reflections. Care is required to prevent intrabeam viewing and control specular reflections. Most military laser rangefinders and designators fall into this category.

(d) Class IV—High power (HP) lasers are those pulsed visible lasers capable of producing diffuse reflections or fire and skin hazards, or those CW lasers with an output above 0.5 W. Safety precautions associated with high power lasers generally consist of using door interlocks to prevent exposure to unauthorized or transient personnel entering the laser facility, the use of baffles to terminate the primary and secondary beams, and the wearing of protective eyewear and clothing by personnel.

(e) Class V—Enclosed Laser (ES)—As the name implies, the laser is enclosed such that potentially hazardous optical radiation does not exit from the enclosure.

(2) This classification scheme is identical to that used in American National Standards Institute "ANSI-Z-136, Safe Use of Lasers, 1973." This classification may already appear on commercial laser products manufactured subsequent to the adoption of that standard and should be used unless the laser is modified to signify change its output power or energy, or unless the laser is enclosed.

c. *Environment.* Following laser/system classification, environmental factors require consideration. Their importance in the total hazard evaluation depends upon the laser classification. The decision to employ additional hazard controls not specifically required in paragraph 8 for class III and class IV laser device depends largely on environmental considerations. The probability of personnel exposure to hazardous laser radiation must be considered and is influenced by whether the laser is used indoors, such as, in a machine shop, in a classroom, in a research laboratory, or a factory production line, or outdoors, such as, on a range, in the atmosphere above occupied areas, or in a pipeline construction trench. Other environmental hazards (Para 9) must be considered. If exposure of unprotected personnel to the primary or specularly reflected beam is expected, calculations or measurements of either irradiance or radiant exposure of the primary or specularly reflected beam (or radiance of an extended source laser) at that specific location are required. These detailed procedures are discussed in appendix D.

(1) *Indoor laser operations.* In general only the laser device classification is considered in evaluating an indoor laser operation if the beam is enclosed or is operated in a controlled area. The following step-by-step procedure is recommended for evaluation of Class III lasers indoors when this is necessary (since there is a potential exposure of unprotected personnel with this particular class of laser devices).

STEP 1. Determine the hazardous beam path(s).

STEP 2. Determine extent of hazardous specular reflection, as from lens surfaces and beam splitters (app D.).

STEP 3. Determine the extent of hazardous diffuse reflections if the emergent laser beam is focused.

STEP 4. Determine is other (non-laser) hazards exist (para 9).

(2) *Outdoor laser operations over extended distances.* The total hazard evaluation of a particular laser system depends on defining the extent of several potentially hazardous conditions. This may be done in a step-by-step manner as follows:

STEP 1. Determine the nominal hazardous range of the laser (app D). The nominal hazardous range of standard lasers is established by the US Army Environmental Hygiene Agency.

STEP 2. Evaluate potential hazards from specular surface reflections, such as those from windows and mirrors in vehicles. Flat surfaces present the greatest problem since specular reflections retain the high collimation of the original laser beam (fig 2 and 3).

STEP 3. Determine whether hazardous diffuse reflections exist if the laser is operating in the 400-1400 nm band (table 2 app B and example 9, app D).

STEP 4. Evaluate the stability of the laser platform to determine the extent of lateral range control and the lateral constraints that should be placed upon the beam traverse. Evaluate need for control of evaluation angle.

STEP 5. Determine the likelihood of personnel being present in the area of the laser beam.

(3) *Personnel.* The individuals who may be in the vicinity of a laser and its emitted beam(s) can influence the decision to adopt additional control measures not specifically required for the class of laser being employed. This depends upon the classification of the laser device.

FIRST. If children or others unable to read and/or understand warning labels may be exposed to potentially hazardous laser radiation, the hazard evaluation is affected, and control measures could require appropriate modification.

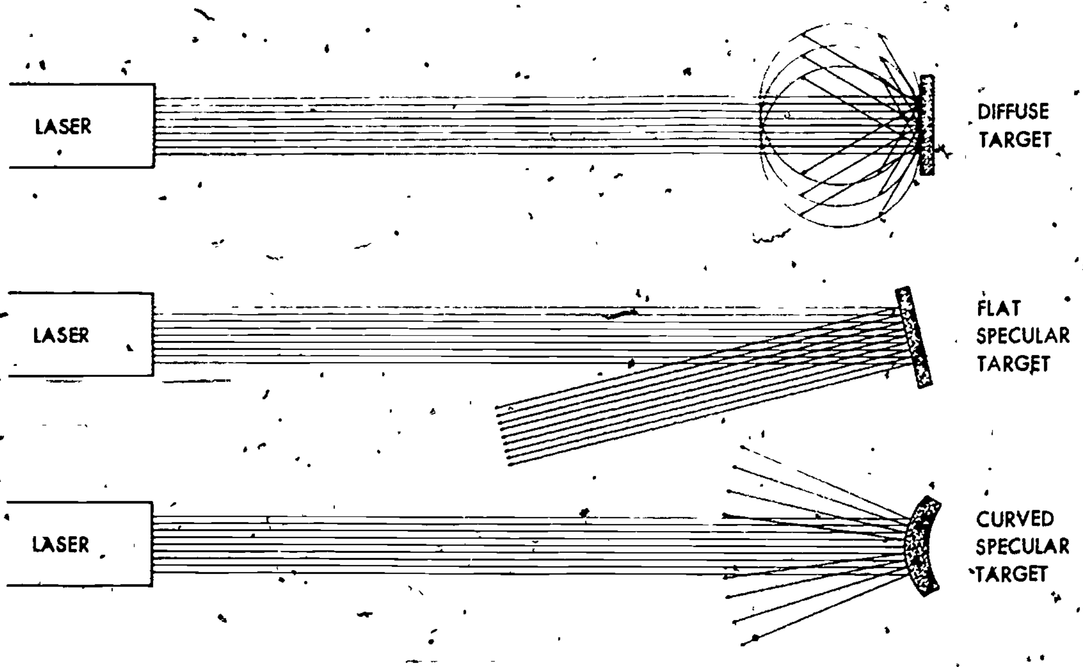


Figure 2. Diffuse reflection and specular reflection

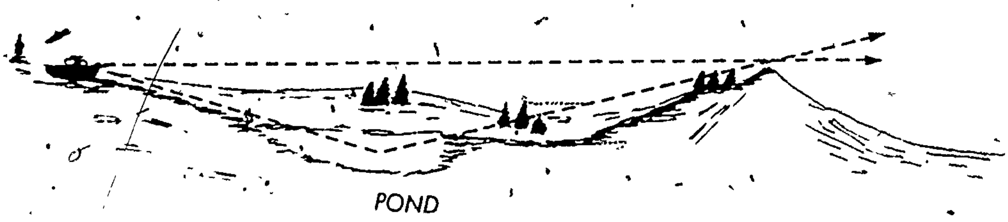


Figure 3. Example of specular reflection from pond of water or horizontal flat glass on range.

SECOND. The type of personnel influences the total hazard evaluation (principally with the use of class III, Medium Power Lasers). *It shall be kept in mind for laser rangefinder, designators and some class III lasers used in construction, that the principle hazard control rests with the operator not to aim the laser at personnel or flat mirror-like surfaces.*

The following are considerations regarding personnel who may be exposed:

FIRST. Maturity and general level of training and experience of laser user(s) (i.e., trainees, experienced soldiers, scientists).

SECOND. Awareness of onlookers that potentially hazardous laser radiation may be present, and their knowledge of relevant safety precautions.

THIRD. Degree of training in laser safety of all individuals involved in the laser operation.

FOURTH. Reliability of individuals to wear eye protection, if required.

FIFTH. Laser exposure that may be intentional for the application.

SIXTH. Number and location of individuals relative to the primary beam or reflections, and probability of accidental exposure.

8. General Hazard Controls For Laser Radiation. *a.* Hazard controls vary depending on the type of laser being used and the manner of its use. Most control measures depend upon the laser classification as specified in appendix C. In general, a class I laser device is one that is considered to be incapable of producing damaging optical radiation levels and is, therefore, exempt from any control measures or other forms of surveillance. A class II Laser device may be viewed directly, but must have a cautionary label affixed to the device warning against continuous intrabeam viewing (staring into the beam).

A class III medium power laser device requires control measures that shall prevent intrabeam viewing. A class IV High Power Laser Device requires the use of controls which shall prevent exposure of the eye and skin to the direct and diffusely reflected beam and the termination of the unused beam (s) by fire-resistant backstops. Class V Enclosed Laser Devices are either class II, class III or class IV lasers contained in a protective housing and operated in such a manner as to be incapable of emitting hazardous radiation from the enclosure. Only a stringent control system permits a laser to qualify as class V.

b. It must be remembered that the classification scheme given in paragraph 7*b* relates specifically to the laser device itself and its potential hazard, based on operating characteristics. However, the environment and conditions under which the laser is used, the safety training of persons using the laser and other environmental and personnel factors, may play a role in determining the full extent of hazard control measures. Since such situations will require informed judgements by responsible persons, major responsibility for such judgements should be assigned to a qualified person, namely a Laser Safety Officer. Only properly indoctrinated persons shall be designated Laser Safety Officers or be placed in charge of class III and IV laser installations or operations The complete enclosure of a laser beam (an enclosed laser) shall be used when feasible. A closed installation provides the next most desirable hazard control measure. Following are details relating to safe laser operation in.—

(1) An outdoor environment where administrative controls often provide the only reasonable approach.

(2) An indoor environment where engineering controls should play the greatest role.

c. Outdoor Laser Installations.

(1) *Class II low power laser devices.* The beam should be terminated where readily feasible at the end of the useful beam path and the laser should not be directed at personnel who are not cognizant of their illumination.

(2) *Class III and IV lasers.*

(*a*) Personnel shall be excluded from the beam path at all points where the beam irradiance or radiant exposure exceed the appropriate Protection Standard. This shall be accomplished by the use of physical barriers, administrative controls, the use of interlocks and by limiting the beam traverse.

(b) The tracking of nontarget vehicular traffic or aircraft, whether intentional or inadvertent, shall be prohibited within the calculated hazardous distances of class III or IV lasers.

(c) The beam path(s) shall be cleared of all flat specular surfaces capable of producing reflections that are potentially hazardous, or eye protection should be required for all personnel within the hazardous area.

(d) Paragraphs 10 and 11 provide detailed guidance applicable to range control of laser rangefinders, illuminators and designators.

(3) *Class IV laser.* Operation of class IV High Power Laser Devices while it is raining or snowing or when there is dust or fog in the air should be avoided without the wearing of laser protective eyewear by personnel within the immediate vicinity of the beam.

d. Indoor Laser Installations.

(1) Class IV, High Power Laser Installations—Specific Precautions. Pulsed class IV visible and IR-A lasers are hazardous to the eye from direct beam viewing and from specular and diffuse reflections of the laser beam, and are generally also hazardous to the skin. Class IV ultraviolet, infrared, and CW visible lasers present a potential fire and skin hazard. Safety precautions associated with high power lasers generally consist of using door interlocks to prevent exposure to unauthorized or transient personnel entering the controlled facility, the use of baffles to terminate the primary and secondary beams, and the wearing of protective eyewear and clothing by personnel within the interlocked facility.

(a) Safety interlocks at the entrance of the laser facility shall be so constructed that unauthorized or transient personnel shall be denied access to the facility while the laser is capable of operating.

(b) Laser electronic-firing systems for pulsed lasers shall be so designed that accidental pulsing of a stored charge is avoided. The firing circuit design should incorporate a "Fail-safe" system in this regard.

(c) An alarm system including a muted sound and/or warning lights (visible through laser protective eyewear) and a countdown procedure should be used once the capacitor banks begin to charge.

(d) Good room illumination is important in areas where laser eye protection is required. Light colored, diffuse surfaces in the room help to achieve this condition.

(e) Very high energy or high power lasers should be operated by remote control firing with television monitoring, if feasible. This eliminates the need for personnel to be physically present in the same room. The enclosure of the laser, the associated beam, and the target in a light-tight box is an equivalent alternative.

(f) The principal hazard associated with high power CW infrared (such as $CO_2 \cdot N_2$) lasers is the fire hazard. A sufficient thickness of earth, firebrick, or asbestos should be provided as a backstop for the beam.

(g) Reflections of far-infrared laser beams should be attenuated by enclosure of the beam and target area or by eyewear constructed of a material, such as Plexiglass which is opaque to laser wavelengths beyond 3 μm. Even dull metal surfaces may be highly specular at far-infrared laser wavelengths such as 10.6 μm (CO_2 laser).

(2) Specific precautions applicable to class III medium power CW or pulsed laser systems. These lasers are potentially hazardous if the direct beam is viewed by the unprotected eye. Care is required to prevent direct beam viewing and control specular reflections. Eye protection is required if accidental intra-beam viewing is possible.

9 Recognition of Associated Hazards. Depending on the type of laser used, associated hazards involved in laser operations may include.

a Atmospheric Contamination. Adequate ventilation or enclosures shall be employed to control:

(1) Vaporized target material from high energy cutting, drilling, and welding operation. Materials involved may include carbon monoxide, carbon dioxide, ozone, lead, mercury, and other metals.

(2) Gases from flowing gas lasers or byproducts of laser reactions such as bromine, chlorine, hydrogen cyanide, and many others Ozone created by laser-produced plasma.

(3) Gases or vapors from cryogenic coolants.

(4) Vaporized biological target materials from high energy lasers used in biological or medical applications.

b Ultraviolet Radiation Either direct or reflected UV radiation from flash lamps and CW laser discharge tubes shall be shielded Ultraviolet radiation is generally only of concern when quartz tubing is used. Personnel shall not be exposed to levels of ultraviolet radiation in excess of protection standards given in AR 40-46.

c Visible and Near-Infrared Radiation. High intensity optical pumping systems may present a potential retinal hazard and should be shielded.

d Electrical Hazards The potential for electrical shock is present in most laser systems. Pulsed lasers utilize capacitor banks for energy storage and CW lasers generally have high voltage direct current or radiofrequency electrical power supplies. Solid conductor grounding rods (connected first to a reliable ground) shall be utilized to discharge potentially live circuit points prior to maintenance. Maintenance personnel shall familiarize themselves with the safety procedures provided in the maintenance manual for the device.

e Cryogenic Coolants. Cryogenic coolants may cause skin or eye injury if improperly used. Examples are: liquid nitrogen, liquid helium, liquid hydrogen.

f Other Hazards The potential for explosions at capacitor banks or optical pump systems exists during the operation of some high power lasers or laser systems. The possibility of flying particles from target areas in laser cutting, drilling, and welding operations may exist Explosive reactions of chemical laser reactants or other gases used within certain laser laboratories is of concern in some cases.

g X rays X rays may be generated from high voltage (over 15 kV) power supply tubes. Adequate shielding shall be employed.

10 Simplified Range Control Measures for Typical Operations of Laser Rangefinders, Designators and Illuminators *a Limitations* The guidance provided deals with range operations in which the laser rangefinder designator or illuminator is aircraft or vehicle-mounted, tripod-mounted or hand-held and has a hazardous range of at least 1 km. Because of the varied characteristics of laser systems in use, these guidelines should not be applied to laser systems other than those having a beam divergence of 1° (17 milliradians) or less.

b. Background.

(1) The laser system except for its inability to penetrate targets can be treated like a direct-fire, line-of-sight weapon, such as a rifle or machinegun. Thus, the hazard control precautions taken with respect to those types of weapon will provide most aspects of the safe environment required for laser use. Special control measures for laser use are discussed below.

(2) The hazard from these types of laser devices is limited to exposure to the unprotected eye of individuals within the direct laser beam or a laser beam reflected from specular (mirror-like) surfaces. Serious eye damage with permanent impairment of vision can result to unprotected personnel exposed to the laser beam.

(3) Essentially, the laser beam travels in a straight line, so it is necessary to provide a backstop, such as a hill behind the target during laser firing. Calculated nominal hazardous ranges often extend even beyond 8 kilometers, and the use of optical viewing instruments within the beam could extend this hazardous range considerably. For this reason, and because of atmospheric effects upon the beam, the designation of a single "hazardous range" for firing range safety purposes is not feasible for most testing and training purposes.

(4) Every object that the laser beam strikes will reflect some energy back toward the laser. In most cases, this energy is a diffuse reflection and is not hazardous, however, certain shiny reflecting surfaces must be avoided as targets to prevent a hazardous amount of radiation from being reflected. These conditions are described in succeeding subparagraphs.

c. Laser Range Safety Officer. A person familiar with the range control procedures required for laser operations is termed in this bulletin the "Laser Range Safety Officer" (LRSO). The LRSO is responsible for the following:

(1) The LRSO will thoroughly instruct all personnel authorized to participate in the laser operation regarding safety precautions to be followed. This instruction should be of such scope as to alleviate any fears generated by a lack of knowledge that may be harbored by participating personnel.

(2) The LRSO will insure that safe standing operating procedures are implemented and will establish target areas with buffer zones at least 2 to 5 mils around the target area as defined by the

greatest laser-to-target distance. The LRSO will provide adequate surveillance of the target area to insure that no unauthorized personnel enter that area. He will insure that communication with personnel in the target area is maintained to insure that protective eyewear is worn as required during operation. Any break in communications will automatically terminate laser operation.

(3) The LRSO is responsible for reporting immediately any case of suspected over-exposure of the eye to laser radiation to the installation surgeon so that an eye examination can be performed within 24 hours of the exposure.

d. *Laser Operator.* The laser operator will fire only at designated targets which are diffuse reflectors, and will at no time fire at specular surfaces, such as glass, mirrors, windows, etc. This constraint can be met by removing, covering or painting specular surfaces on vehicles.

e. *Eye Protection.* Those who must be in the target area, such as moving target operators or test personnel, shall wear laser protective eyewear with curved protective lenses during laser firing. Such eyewear must be approved for the specific model of laser device being fired. A laser filter designed for protection against one type of laser may not protect against harm from another.

f. *Inclement Weather and Night Operations.* No precautions other than as previously stated in paragraph 10 are required at night, or during rain, snow or fog.

g. *Operation Outside of Range Area.* The laser system will not be operated or experimented with when removed from its mount, such as a tripod or vehicle unless specifically authorized by the appropriate maintenance manual.

h. *Beam Termination.* During laser operations no portion of the laser beam will extend beyond the controlled target area. This will be done by construction of the target or choosing a natural target, the size of which will intercept the laser beam and provide an additional buffer zone. Targets will be located in such a manner that they have a geographical backstop, i.e., a mountain or the ground.

i. *Buffer Zone.* The extent of the buffer zone depends upon the aiming accuracy of the laser device. The aiming accuracy of the laser device depends upon whether the laser is mounted on a stable platform, i. e., a static base that cannot be easily moved by someone jarring it (e. g., heavy-duty tripod, static tank, reinforced bench mount) or an unstable platform (e.g., light tripod, hand grip, moving tank or aircraft). The stable platform generally requires only 2 mil buffer zones, whereas, the unstable platform generally requires 5 mil buffer zones. For moving platforms without gyro-stabilization, 10 mil buffer zones may be required.

j. *Optical Viewing.* The use of optical devices to observe the target during laser operation will not be permitted unless flat specular surfaces have been removed from the target area or unless appropriate laser safety filters are placed in the optical train of the binocular or telescope.

k. *Countdown.* A countdown is not required prior to firing in a range environment The use of range flags during firing serves the purpose of notifying personnel that laser firing or live firing is in progress. Radio communication with personnel downrange in the target area must be provided during laser operation to insure that eye protection is being worn by such personnel.

l. *Standing Snow and Water.* Hazardous specular reflections from standing snow or water do not present a hazardous situation to ground personnel not located along the azimuth of the beam path. These reflections do not present a hazard to personnel in aircraft outside of the restricted air space above the range.

m. *Warning Signs.* Evaluation of each anticipated operating condition should include consideration and development of procedures for insuring proper placing of warning signs for that operation. Local standing operating procedures should provide for the placement of temporary or permanent signs during such periods of operation The symbol is red with black lettering on white background.

n. *Ground Laser Systems—Specific Guidance*

(1) No unprotected personnel will be permitted in the laser target area as shown in the "surface danger area" diagram (fig 4) for the range as would be utilized for a live fire weapon (e. g., AR 385-63).

(2) The laser device will be fired only on ranges that have been established as laser ranges If the laser system is to be used on a non-live-firing range, Area B may be omitted from the surface danger area diagram.

(3) The laser device will not be used in two-sided tactical excercises unless all personnel are equipped with appropriate laser eye protection.

(4) For laser firings, the dimensions of the target and impact areas created by the direct-fire-weapon safety requirements (e. g., AR 385-63) must be extended by an additional zone, area C of figure 4. Area C can be shortened or eliminated by the use of a suitable backstop located beyond the targets (targets will be suitably placed below the horizon of the backstop, fig 5). To prevent the need for control of airspace to the nominal hazardous range (typically 5 to 20 kilometers), the laser should only be fired from a static position when it is pointed more than 2 mils below the backstop horizon or fired from a moving vehicle when it is pointed more than 5 mils below the backstop horizon.

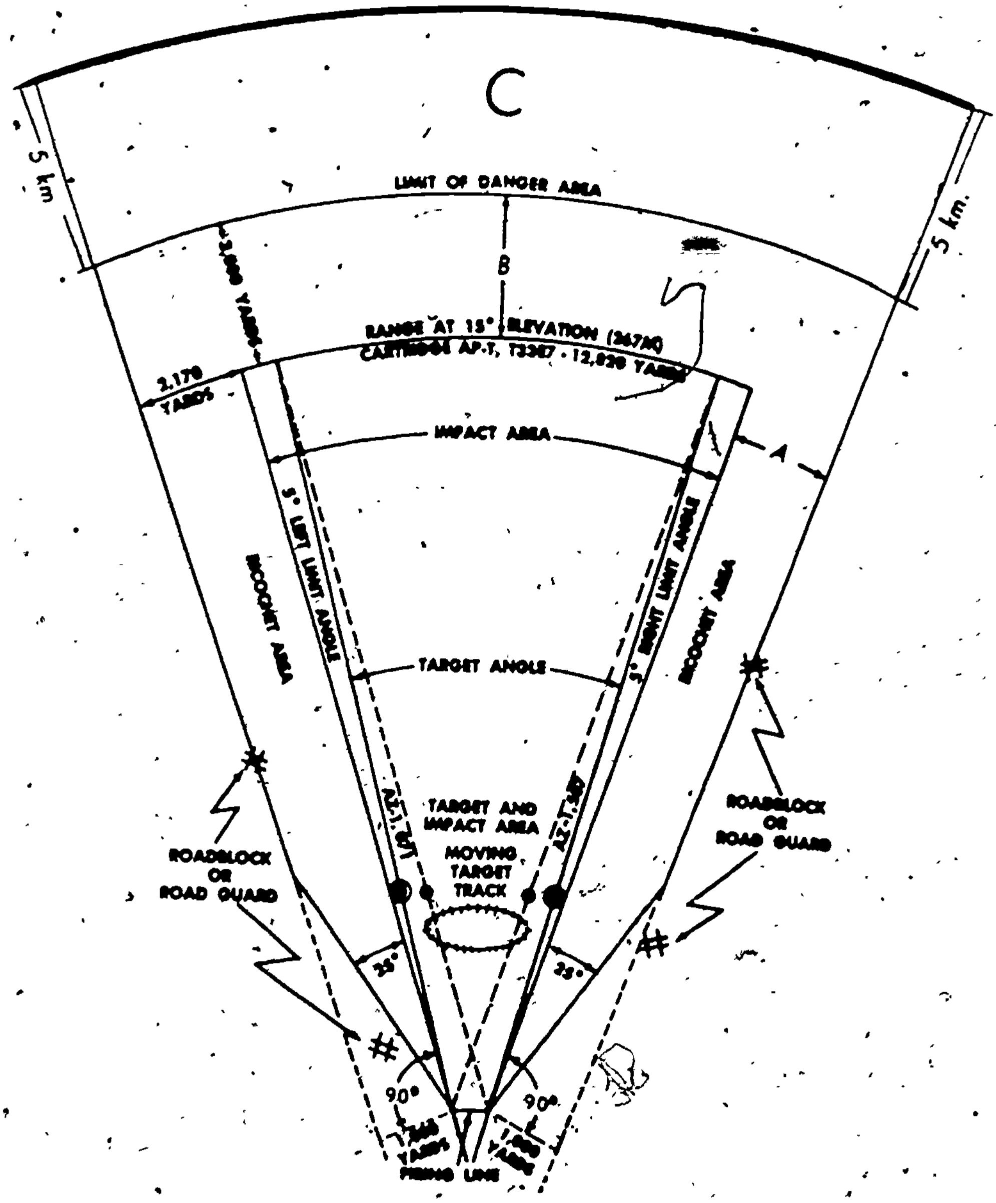


Figure 4. Surface area danger diagram with area C added.

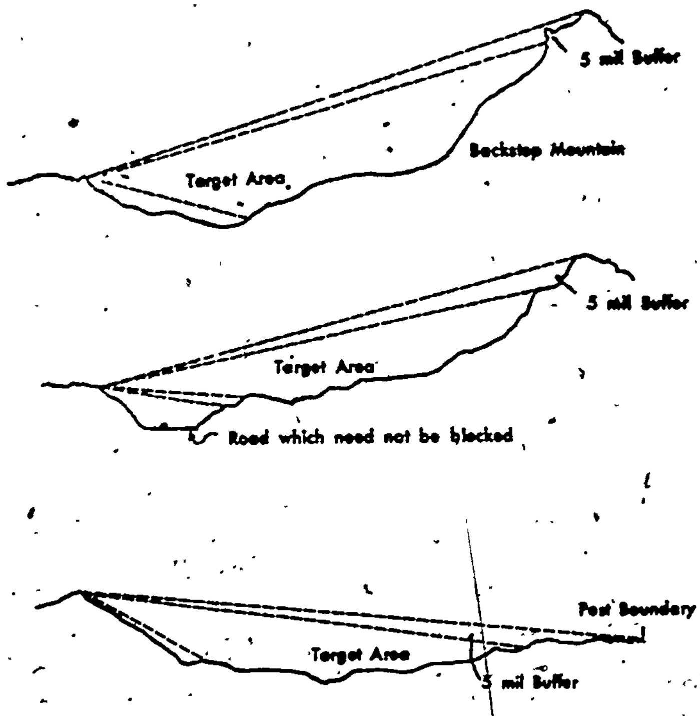


Figure 5. Laser range terrain profiles with backstops.

(5) Barricades and warning signs used to prevent personnel from entering a weapon-firing area will also be used for that same purpose in conjunction with laser firing. The additional requirements posed by the laser in this regard are to mark extended range areas (area C) if one is required, and to provide notice (fig 5) at the entrance to the range that laser operations are being conducted.

(6) Flat mirror-like objects having a vertical or near-vertical surface must be removed from the target area between 0 and 1000 meters from the firing point farthest downrange to prevent eye injury from a reflected laser beam. Generally, those surfaces in which a reflected image can be ovserved should be removed, but the object may be covered or painted with lusterless paint if it cannot be removed. Flat mirror-like objects in the sense of this provision are:

(a) Mirrors.

(b) Chrome-plated metal.

(c) Panes of glass or plastic (e. g., Lucite or Plexiglass).

(7) Beyond, 1000 meters range, only clearly visible reflective objects need to be removed if the beam divergence is less than 0.6 milliradian. However, the laser range finder should not be *intentionally* fired at highly reflective surfaces at any range.

(8) The target material may be of any surface that does not meet the description in *f* (6) above. Cloth, cardboard, wood and lusterless metal of any size and color are acceptable as targets for laser firing.

(9) To prevent potential hazards to unprotected personnel from diffuse reflections, some laser devices should not be fired at any surface located within a range of 10 meters from the laser. Precautions such as the removal of brush and trees necessary to prevent this should be taken.

(10) The filters and protective goggles that have been developed for use with lasers are not required for training exercises when all personnel outside of the target area comply with the provisions of this bulletin. Persons who must be in the target area must wear laser protective eyewear with curved protective lenses.

(11) An opaque dust cover or ballistic cover shall be in place whenever the laser device is removed from the range.

o. Laser, Operations from Aircraft. These guidelines apply to operation of airborne laser rangefinder and designators aimed at ground targets which can cause ocular injury to ground personnel observing the laser source directly, or indirectly by specular reflection, at most operational altitudes.

(1) It is generally desirable to clear the target area of flat specular surfaces. The pilot of the aircraft

assigned to fly the firing area will be instructed to visually check for possible specular items before laser operation by noting the location of standing water and the position of vehicles and buildings which may contain glass.

(2) Laser protective eyewear with curved filter lenses will be made available for personnel required to be in the vicinity of the target area during laser operation. The safety goggles will provide an optical density appropriate for the operation at the laser wavelength. For devices having an output energy pulse less than 0 1 joule, an optical density of six is adequate.

(3) The use of laser eye protection by air crew personnel which reduces vision shall be discouraged, other hazard controls should be utilized instead.

(4) The installation surgeon will be notified prior to laser operations so that personnel required to receive a thorough ophthalmological examination prior to working with the laser, as outlined in paragraph 5, can receive such examinations.

(5) The flight crew will take all precautions to insure that the laser is fired only at designated targets.

(6) All ground personnel must be instructed to assume that the laser is in operation at all times whenever the aircraft is firing on targets or is above an active range.

(7) The officer in charge or operator will insure that the laser system is secured and unable to fire when the aircraft is in some location other than an authorized firing site.

(8) The Laser Range Safety Officer and local air traffic control will assure that adequate danger zones are established and that strict control of traffic is maintained as necessary. Normally, a Range Control Office is responsible for coordinating the mission with other activities within the laser operational area and for furnishing all required information to control tower operators and unauthorized ground control stations associated with the mission. The LRSO is responsible for thoroughly briefing all pilots prior to their engaging in any mission within the danger area, the briefing to include geography of the area, access and exit routes, limits of flight pattern, radio frequencies to be employed and applicable local procedures. Whenever practicable, each pilot assigned to a training mission will make a dry run prior to the mission in order to become acquainted with the prescribed course and the test area.

(9) Do not initiate laser operation at ranges where a 5 mil buffer zone will not exist on all sides of the target within the government controlled property area.

p. Hangar, Garage, and Maintenance Shop Procedures.

(1) All testing performed in shop areas will be strictly controlled with barriers and signs.

(2) Firing of the laser in shop areas should be into a light-tight box expressly designed to contain all of the laser output where feasible.

(3) The maintenance officer will insure that the number of operating personnel on the site for testing does not exceed that necessary to accomplish the task safely and efficiently. Transient personnel are restricted to those having an official interest in the test and must be cleared by the maintenance officer.

(4) Check tests requiring laser operation over an extended distance (i.e., 100 m to 1000 m) may be conducted in occupied areas only under strict controls to insure that the beam can only travel along a tightly controlled path defined by a beam aperture located at 1 m and 10 m from the laser (fig 6).

11. **Personnel Protective Equipment.** *a.* Personnel whose occupation or assignment require exposure to laser beams should be furnished through local procurement supply channels suitable laser safety goggles which will protect for the specific wavelength of the laser and be of optical density (O.D.) adequate for the energy involved. Table 2 lists the maximum power, energy, irradiance or radiant exposure for which adequate protection is afforded by filters of optical densities from 1 through 8. Eye protection should have curved lenses to reduce specular reflection hazards.

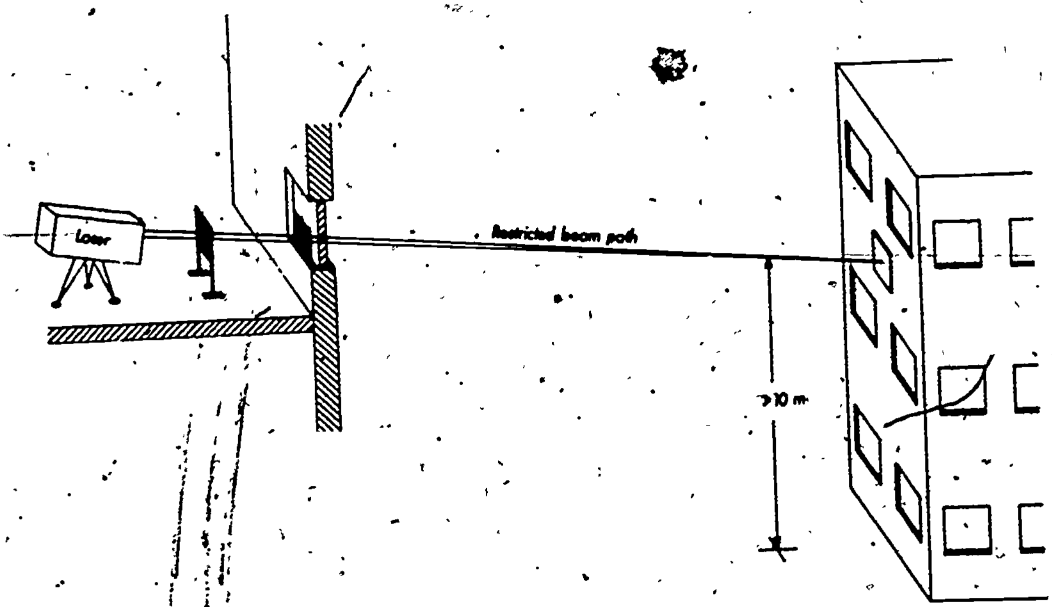


Figure 6. Maintenance test range established by limiting beam elevation and azimuth to insure that beam strikes a diffuse backstop. Beam path is above occupied areas.

Table 2. Simplified Method for Selecting LASER Eye Protection for Intrabeam Viewing for Wavelengths Between 200 and 1400 nm

Q-Switched lasers (1 ns to 0.1 ms)		Non-Q-switched lasers (0.4 ms to 10 ms)		Continuous lasers momentary (0.25 s to 10 s)		Continuous lasers Long-term staring greater than 3 hrs		Attenuation	
Maximum output energy (J)	Maximum Beam radiant exposure ($J \cdot cm^{-2}$)	Maximum laser output energy (J)	Maximum beam radiant exposure ($J \cdot cm^{-2}$)	Maximum power output (W)	Maximum beam irradiance ($W \cdot cm^{-2}$)	Maximum power output (W)	Maximum beam irradiance ($W \cdot cm^{-2}$)	Attenuation factor	OD
10	20	100	200	NR	NR	100	200	100,000,000	8
1.0	2	10	20	NR	NR	10	20	10,000,000	7
10^{-1}	2×10^{-1}	1.0	2	10^3	2×10^3	1.0	2	1,000,000	6
10^{-2}	2×10^{-2}	10^{-1}	2×10^{-1}	100	200	10^{-1}	2×10^{-1}	100,000	5
10^{-3}	2×10^{-3}	10^{-2}	2×10^{-2}	10	20	10^{-2}	2×10^{-2}	10,000	4
10^{-4}	2×10^{-4}	10^{-3}	2×10^{-3}	1.0	2	10^{-3}	2×10^{-3}	1,000	3
10^{-5}	2×10^{-5}	10^{-4}	2×10^{-4}	10^{-1}	2×10^{-1}	10^{-4}	2×10^{-4}	100	2
10^{-6}	2×10^{-6}	10^{-5}	2×10^{-5}	10^{-2}	2×10^{-2}	10^{-5}	2×10^{-5}	10	1

b. Needless exposure of the skin of personnel should be avoided. When the hands or other parts of the body must be exposed to potentially hazardous levels, protective coverings, gloves, or shields shall be used. The face should be turned away from the target area. Laser welding and cutting facilities should have sufficient shielding surrounding the article being welded.

c. Impervious, quick removal gloves, face shields, and safety glasses should be provided as protection for personnel who handle the extremely low temperature coolants which may be used in higher powered lasers.

12. **Requests for Technical Assistance and Accident Reporting.** The Surgeon General, Department of the Army, is responsible for evaluating potential health hazards to personnel operating, testing, or otherwise associated with lasers. Activities should request assistance in evaluating these hazards from:

a. *Accident Reporting.* Accident reporting should be in accordance with AR 385-40, chapter 11.

b. *Technical Assistance.* The services of the US Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD 21010, are available upon written request (through appropriate command channels) to Commander, US Army Health Services Command, ATTN: HSC-PA-H, Ft Sam Houston, TX 78234.

c. *Biological Data.* The USAMRDC/AMC Joint Laser Safety Team, Frankfort Arsenal, conducts research and development to obtain data on the bio-medical effects of laser radiation. Biological research data required for the safety evaluation of new types of lasers is available to development agencies upon written request to: Chief, USAMRDC/AMC Joint Laser Safety Team, W-1000, Frankfort Arsenal, PA 19137.

APPENDIX E

WARNING SIGNS AND LABELS FOR LASERS

1. SCOPE. The guidance provided is based upon the laser classification system.

2. GENERAL. Warning signs shall be conspicuously posted at access points to potentially hazardous laser areas in accordance with local standing operating procedures for Class III medium and Class IV high power lasers. A warning label shall be prominently affixed to the laser or laser system housing for all Class II low, Class III medium, and Class IV high power laser devices.

3. FORMAT. Examples of various laser signs and labels are shown in figures 1 through 6. Warning signs and labels shall use the word "CAUTION" for Class II low power laser devices and Class IIIA medium power CW visible lasers having a maximum emergent beam irradiance of 2.5 mW/cm^{-2} averaged over a 7 mm aperture and an output power between 1 and 5 mW. Warning signs and labels shall use the word "DANGER" for Class IIIB medium and Class IV high power laser devices except as noted above. Warning signs and labels should include other pertinent information including the type of laser and appropriate control measures to insure personnel safety.

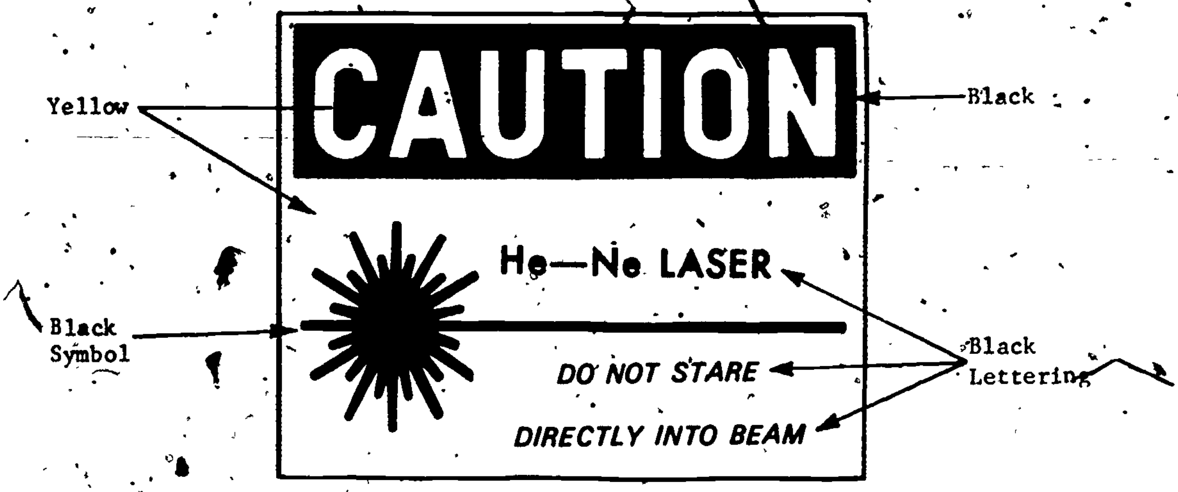


Figure 1. Example of Warning Label for a Class II Low Power Laser Device.

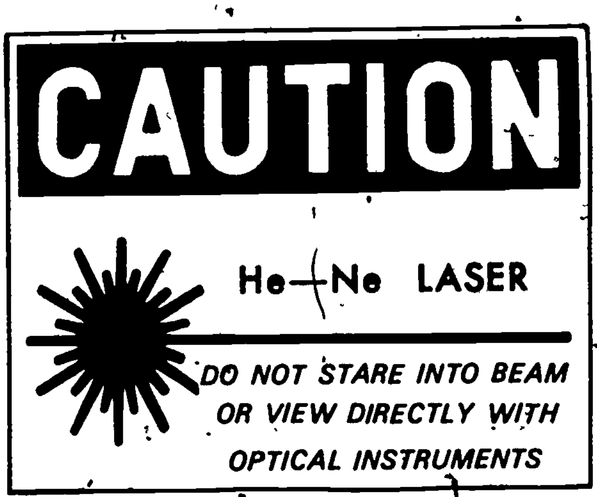


Figure 2. Example of Warning Label for a Class IIIA Medium Power Laser Device.

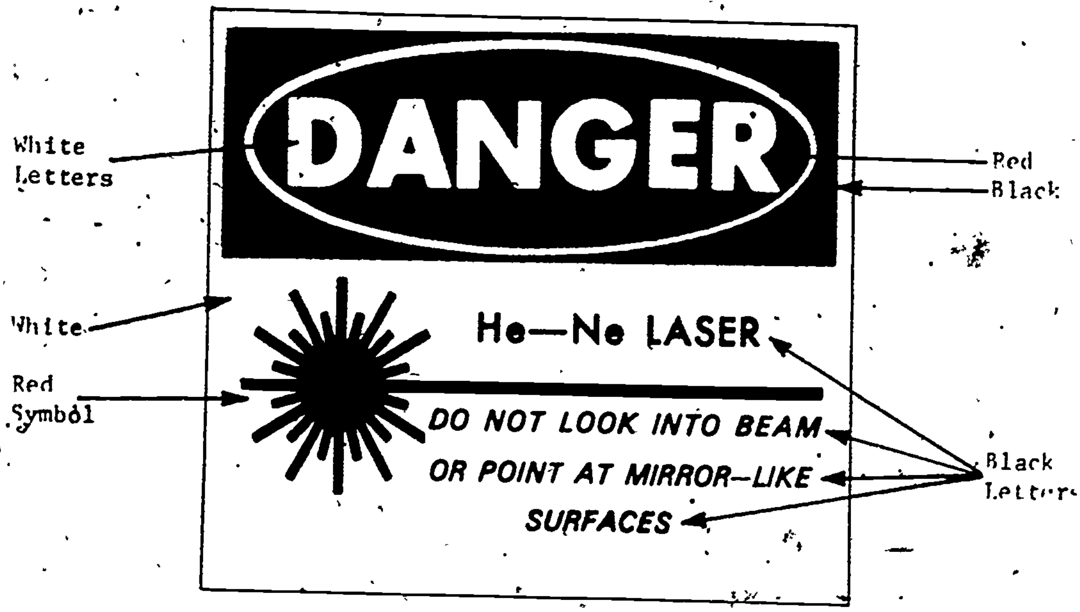


Figure 3. Example of Warning Label for Class III B Medium or Class IV High Power Laser Devices.

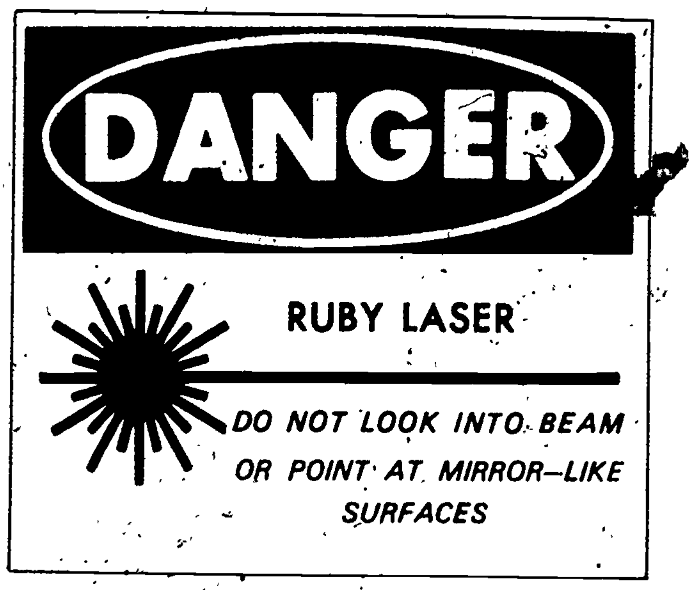


Figure 4. Example of Warning Label for Class III B Medium or Class IV High Power Laser Devices.

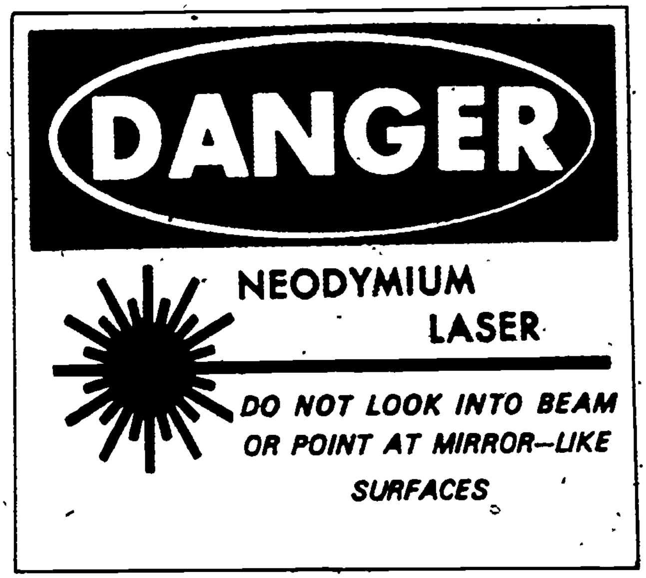


Figure 5. Example of Warning Label for Class III B Medium or Class IV High Power Laser Devices.

Figure 6. Example of Warning Sign for a Class III B Medium or Class IV High Power Laser Devices.

MICROWAVE RADIATION
AND
SAFETY PROCEDURES

DF460

DF460, MICROWAVE RADIATION AND SAFETY PROCEDURES

MICROWAVE RADIATION AND SAFETY PROCEDURES

I. References and Discussion.

A. References:

1. AR 40-583, Control of Potential Hazards to Health from Microwave Energy.

2. TB MED 270, Control of Hazards to Health from Microwave Radiation.

3. Course Manual, Laser and Microwave Hazards, US Army Environmental Hygiene Agency, APG-EA 21005.

B. Discussion:

1. General.

a. Electromagnetic radiation having a wavelength in the microwave region, 1 meter to 1 millimeter, with corresponding frequencies 30-300,000 MHz (megacycles/second).

b. Biological effects are different from ionizing radiation. Microwave radiation is similar to infrared radiation in that it causes heating of the skin and underlying tissue. There is no genetic carryover.

c. Sources.

Radars, lasers, oscillators, microwave ovens, and other equipment emitting radiation in the microwave region of the spectrum.

2. Nature of Microwave Radiation.

a. Existing radar systems, lasers, oscillators, e.g., klystron tube, microwave ovens, utilize the portion of the electromagnetic spectrum included within the approximate frequencies of 100-100,000 MHz. In its proper place in the electromagnetic spectrum, the "microwave" region is located between infrared (10^6 MHz) and VHF radio (10 MHz) regions.

b. It is far removed in frequency from the ionizing radiation class of X-rays (10^{10} MHz) and gamma rays (10^{13} MHz). Consequently, microwave radiation has never been observed to cause ionization and is classified as "non-ionizing" radiation.

c. An important consideration is the combined effects of heating and penetration on a biological system such as the human body. Microwave radiation produces electrical and magnetic forces and generates heat. The heat and forces may, if sufficiently intense, have profound effects. Although these effects can be used to good advantage, they are potentially dangerous and must be given careful consideration.

3. Biological Aspects.

a. Microwave radiation does not cause ionization, but causes excitation of atoms with resultant production of heat. The depth of heating is frequency-dependent. Refer to Table I.

b. Biological experimentation indicates a temperature rise when heating is produced by sufficient absorption of microwave energy. The rate of temperature rise is dependent upon the quantity of the absorbed radiation and the ability of the experimental animal to dissipate heat. As the animal reaches a point where it can no longer compensate for and dissipate the neat generated, the animal will die if radiation is continued. If the radiation ceases before the heat control mechanism breaks down, the animal will recover with no demonstrable residual effects. A similar sequence can occur in man but there is no assurance that the values for animals will apply to man due to the difference in heat control mechanisms.

c. Man has a much more complex and efficient heat control and heat dissipation mechanism than the experimental animal. Experimentally when man has been exposed to 100 mW/cm^2, his temperature will actually fall while there is a definite rise in that of the animal. Thus, the quantity of absorbed energy required to produce changes in man is probably higher than that in animals.

d. Most Susceptible Parts of the Human Body.

(1) Testicle. A change of a few degrees will cause cessation of sperm production. When radiation is removed, the effect ceases and sperm production is resumed.

(2) Lens of the eye lacks an efficient circulating system, thus it cannot dissipate heat as readily as the rest of the body. If there is enough cellular destruction of the eye lens, clouding (cataracts) occur.

TABLE I

BIOLOGICAL EFFECTS OF MICROWAVES

Frequency (MHz)	Wave Length (cm)	Site of Major Tissue Effects	Major Biological Effects
Less than 150	Above 200		Body is transparent to waves above 200 cm
150 - 1,200	200 - 25	Internal body organs	Damage to internal organs from overheating
1,000 - 3,300	30 - 10	Lens of the eyes	Lens of the eye particularly susceptible and tissue heating
3,300 - 10,000	10 - 3	Top layers of the skin, lens of the eye	Skin heating with the sensation of warmth
Above 10,000	Less than 3	Skin	Skin surface acts as reflector or absorber with heating effects

NOTES:

1. Biological effects listed above result from short massive or prolonged repeated direct exposure exceeding safe limits.

2. Depth of penetration in human body $= \frac{1}{10}\lambda$.

e. Unexplained effects, other than thermal, have been reported, e.g., "pearl-chain" effect in body fluids, nausea in man due to radiation fields below thermal effects; however, these effects have no application to man in the area of microwave hazard.

4. Exposure Criteria.

a. Historically, a single death attributed to microwave has been reported. A radar worker died from "cooked liver"; however, a careful review of the data raises some doubt whether the death was attributable to microwave exposure. There is no question, though, that microwaves are capable of producing serious and even fatal effects.

b. Until 1965-66 both the military and private industry have limited the exposure of personnel to microwave radiation to power density levels no greater than 10 mW/cm^2. The maximum permissible exposure level was the same regardless of the duration of the exposure. The increasing power output levels in newer microwave systems and certain tactical requirements of the military had combined to make this limit difficult to maintain. Therefore the previous accepted maximum permissible exposure of 10 mW/cm^2 for continuous exposure was modified and new criteria adopted which equates higher exposure levels with time of exposure.

The United States Army and Air Force and the C-95 committee of the American National Standards Institute have adopted new standards which relate the level of exposure to the time duration of such exposure. The ANSI standard allows exposures up to 1 mW/cm^2 for any 0.1-hour period. The Army - Air Force allows exposures exceeding 10 mW/cm^2 to be based on the following equation

$$Tp = \frac{6000}{W2}$$

Where:

Tp = permissible exposure time in minutes during any 1-hour period.

W = power density in the area to be occupied (mW/cm^2).

It should be noted that the ANSI standard gives no upper limit as to power density, while the military regulations allow no exposure above 100 mW/cm^2. Areas where power densities greater than 100 mW/cm^2 exist are considered hazardous and designated as denied occupancy areas.

c. It is interesting to note that USSR in 1960 reported their maximum permissible exposure level as 0.01 mW/cm^2 if exposure is for an entire day. They reported a number of general effects due to chronic exposure: slowing of the heart, hypertension, superthyroidism, exhaustion of the central nervous system, and others.

5. Protection.

a. Adequate planning and facility layout to preclude exposure to more than 10 mW/cm^2. Whenever possible, a preliminary survey should be made while feeding the system with a low power source. This will allow location of concentrated power densities. If these areas cannot be shielded, suitable signs should be posted.

b. Suitable instruments to monitor levels of microwave output. As an expedient, the NE-2 neon tubes can be used. Neon tube will fluoresce with power density of approximately 20 mW/cm^2.

c. Protective goggles with proper wavelength protection and with proper optical density. Protective eyewear is available from several commercial sources.

d. Protective clothing is used by radar workers who work in high power R-F environment. The clothing incorporates a continuous metallic material, which acts as a reflector to the microwave.

II. Lesson Objectives and Notes.

A. Objectives:

1. Knowledge of the nature of microwave radiation and its sources.

2. Knowledge of microwave mechanism of damage and resulting physiological effects.

3. Knowledge of military and civilian exposure criteria.

4. Proper monitoring for any excessive microwave radiation and protective measures required.

B. Notes:

RADIATION PROTECTION
OFFICER CASE STUDIES

DF470

DF470, Radiation Protection Officer Case Studies

I. Reference: None

II. Discussion: None

III. Handouts: See attached handouts.

IV. Problems: None

V. Solutions: None

RADIOLOGICAL PROTECTION OFFICER CASE STUDIES

GENERAL SITUATION:

Upon completion of the Radiological Safety Course at Aberdeen Proving Ground, Maryland, you have been assigned as Post Radiological Safety Officer at Camp Swampy, Louisiana. Camp Swampy is a medium sized post with a troop training mission. Assigned to the post besides the training commands are an infantry division and various logistics and supply units.

When you arrive at Camp Swampy, you meet with the outgoing RPO, MAJ Goodtime. You do not get a chance to talk in detail about the Radiological Safety Program on post because MAJ Goodtime is catching a plane in 1 hour. He does introduce you to your staff and shows you the Radiological Safety SOP which he was developing.

The next day, while talking with your operations NCO, you discover that MAJ Goodtime did not push his Radiological Safety Program.

SITUATION NO 1

Mr. Diddle, chief warehouse clerk to the Post Supply System, has just called you. He has just received a shipment of 1,300 compasses. He noticed a number of broken and missing lenses. He has been calling people all morning about the compasses and you are the tenth person to whom he has talked. So far, nobody has been able to tell him what to do. He is relatively new in his job, has never handled radioactive materials, and knows nothing of the safety procedures involved. When you go to the warehouse you notice in the room with the compasses is the entire supply of photographic film for the Post Signal Center's photographic facility. What actions do you now take?

SITUATION NO 2

In January, 1969, Unit ____ requested disposition instructions for three radiac AN/PDR-27(J) sets through supply channels. Reply to this request was for the unit to turn in the items to the Post Consolidated Supply which in turn was to ship the items to depot ________________. It is now February, 1970, you have been working on the leak test report to submit to CONARC. You notice that Unit ________ is 11 months overdue on a wipe test for three of their MX1083 check sources. Upon contacting the unit, you find that the supply clerk in the unit thinks that the items were turned in. As RPO, what do you do, since you still have this source charged to your installation?

SITUATION NO 3

You have just received a call from the Post Consolidated Supply and were informed that they had a TS-784 radiac calibrator sitting in their warehouse. They ask you what to do with it. Upon investigating, you determine that the item has been on post for the past 70 days. You also notice that one corner of the cardboard box shipping container is damaged. As RPO, what do you do about this situation?

SITUATION NO 4

The chief of the Electronic Maintenance Division, Post Maintenance Directorate, just called you on Monday morning and informed you that one of his employees had put his film badge next to the source of one of the TS-784 radiac calibrators on Friday at the close of business and that the badge had remained adjacent to the source all weekend. As RPO, what do you do?

SITUATION NO 5

A temporary employee at the Post Central Storage Warehouse was involved in the movement of a shipment of lensatic compasses. When the film badges were developed, it was discovered that the man received a significant dose of radiation. The man, at this time filed for compensation, because of his high dose exposure. You as RPO have been notified. What action do you take?

SITUATION NO 6

You have just received a telephone call from an Army Reserve unit located about 200 miles from your installation. They desire to borrow 15 AN/PDR-27's from you to use in a CBR school they are conducting. They desire the complete set, including the MX7338 check source. What do you do as RPO?

SITUATION NO 7

The hospital safety officer has called you and requested instructions on how to procure a radium source for the hospital. He also requests information on storage and handling of the source. The hospital has never used radium sources in treatment. What information do you give?

SITUATION NO 8

Unit _______ has been on a field training exercise. Upon returning to garrison the commo maintenance NCO reported that the MX7338 from one of his AN/PDR-27 radiac sets was missing. A search of the area failed to turn it up. You have been notified. As RPO, what do you do?

SITUATION NO 9

During a wipe test of a TS-784 radiac calibrator by one of the workers at the Post Signal Maintenance Facility, a cotton swab and about 1 inch of the stick were broken off inside the source port. You have been asked to render assistance in this matter. What action do you take?

SITUATION NO 10

The installation hospital has turned in to the Post Consolidated Supply an item for disposal. The item is an adaptometer, radioactive plaque (used to test night vision of pilots). According to TB 750-237, Identification and Handling of Radioactive Items in the Army Supply System, this device contains 4.5 μc of ^{226}Ra. You determine that this is a type II item. The item was packaged up and disposition instructions requested in accordance with AR 755-15. You had packaged the item as an exempt quantity; however, upon receiving the disposition instructions, you noted that APG-EA specified that the item should be packaged in a specification 19B package. As RPO, what action do you take?

SITUATION NO 11

A service school is located on your installation. After a group of students departed, maintenance personnel were cleaning out student wall lockers and an MX1083 check source was found. The source stick was broken in half. You have been notified of this event. As RPO, what action do you take? What do you do if the source is leaking?

SITUATION NO 12

Your installation contains a research facility that utilizes radioisotopes in bulk quantities. One day you notice a truck from a commercial trucking firm delivering a shipment of 4 curies of ^{82}Br. The truck has no signs on it identifying it as carrying radioactive material. The driver has no special instructions telling him what to do in an emergency. For example, what action to take in case he has an accident. As RPO, what action do you take?

SITUATION NO 13

You received a call from the range officer. He states that two hunters found what looks like an ammunition igloo surrounded by barbed wire with radioactive material signs posted around it. Upon investigating the igloo, you find that it was an old storage area for radioactive material. Inside you find numerous isotopes which cannot be identified by markings. The only equipment available to you at your installation is the AN/PDR-27. What action do you take? Your installation has multiple radiation sources but no NRC license (no Isotope Committee).

SITUATION NO 14

One of the tenant units on post, the 54th Infantry Division, currently has three TS-784A/PD radiac instrument calibrators. The only individual in the division who is qualified to sign for the calibrators from Lexington Army Depot is the 21st Maintenance Battalion assistant S3, a Chemical Corps first lieutenant. He has just called and informed you that he is on orders to Germany and will be leaving post in 10 days. The only other person on post qualified to sign for the calibrators is yourself. The 21st Maintenance Battalion is currently doing all the calibration for the entire post. What actions do you take?

SITUATION NO 15

During your annual physical yesterday you had a chest X-ray at the post hospital. You noticed the X-ray room did not look quite right and upon closer inspection and comparison with TB Med 62, you determined that it did not meet the necessary safety requirements. You immediately went to see the hospital radiologist who refused even to discuss the X-ray facilities with you. You then went to the hospital commander. He said he did not agree with you, that in his opinion the X-ray room was perfectly safe. He could not even remember ever seeing a copy of TB Med 62. He said there was too much of a demand for the X-ray machine for him to even consider shutting it down. With that statement, he decided the conversation was over, and you left his office. What actions do you take?

SITUATION NO 16

SGT Williams from the Post Signal Center has just called you regarding radioactive electron tubes. Up to now, the signal personnel have simply been throwing burned-out tubes in with ordinary trash. This morning a newcomer to the Signal Center mentioned that he had been told in maintenance school that all radioactive material had to be disposed of separately. SGT Williams talked to the Post Signal Officer who told him to call you for advice. What actions do you take?

SITUATION NO 17

The post safety director read an article in a newspaper about a watch repair facility in one of the major cities being contaminated with radioactive material. He requested that you make a survey of the post watch repair facility to be sure it was not contaminated. Upon performing your survey, you found that the shop was indeed contaminated. All the drop cloths, table tops, floors, and storage cabinets were heavily contaminated with radium which had been deposited from watches over the years. As RPO, what action do you take?

SITUATION NO 18

You have just received a call from the Civilian Personnel Office on your installation and were told that a DAC employee had filed a suite for damages against the Government. The DAC claims that he has skin sores and lesions on his hands and fingers caused by radiation exposure he obtained while working as a member of the Electronics Branch, Post Maintenance Directorate. Your installation now holds two NRC licenses and an ionizing radiation control committee has been formed. As RPO, what do you do?

SITUATION NO 19

You have just received a call from the Post Safety Director's office. The message was that the post property book officer, a civilian, while inventorying the items in his property book, had found a metascope locked in a safe in one of his warehouses. The device had a radiation symbol on it and the isotope was ^{90}Sr. Quantity was not marked; however, the date of manufacture was marked as 1945 and a leak test label had a date of 1955 on it. As RPO, what action do you take?

SITUATION NO 20

One day while visiting the Post Signal Calibration Facility, you observed 19 AN/PDR-27's setting on a table in the shop waiting for calibration. You also noticed that many of the radiac sets did not have the MX7338 check sources attached to the sets' carrying cases by a cord or chain. As RPO, what action do you take?

ACCELERATORS

DF480

DF480, Accelerators

I. References: Accelerators, USAEC Division of Technical Information Pamphlet

II. Lesson Objectives and Notes:

A. Nature of operation of most common types of accelerators.

B. Special hazards of accelerators.

C. Jurisdictional agencies involved in accelerator safety.

D. Publications governing accelerator safety.

Notes:

Notes:

III. Handouts: None

IV. Problems: None

V. Solutions: None

NUCLEAR ACCIDENT CONTROL

DF490, Nuclear Accident Control

I. Reference:

Skim FM 3-15; ST 3-155, Table I-2.

II. Objectives and Notes:

A. Control Responsibility.

B. Actions to be taken.

C. Special Teams.

NOTICE

TO MEDICAL AUTHORITIES

1 - RADIOACTIVE MATERIAL MAY BE PRESENT IN CONTAMINATION.

2 - USE ALL POSSIBLE CARE TO PREVENT SPREAD OF CONTAMINATION.

3 - CLEAN WOUNDS VERY THOROUGHLY, DEBRIDEMENT MAY BE ADVISABLE.

4 - MEDICALLY, PATIENT SHOULD BE HANDLED LIKE ANY OTHER CASE.

DEPT OF ARMY
WASHINGTON 25, D. C.

NOTE. Tag above is 3" x 5" card with wire

III. Handouts:

1. Definitions.

a. A nuclear accident is an unexpected event involving a nuclear weapon or component, resulting in any of the following:

(1) Loss or serious damage to the weapon or component.

By serious damage we mean damage sufficient to render a nuclear weapon or component unsafe or nonoperational to an extent which requires major rework or complete replacement.

(2) Nuclear or non-nuclear detonation of the weapon.

(3) Radioactive contamination.

(4) Public Hazard.

A public hazard is defined as a condition wherein there exists a certainty that the civilian community will be adversely affected.

b. A nuclear incident is an unexpected event involving a nuclear weapon, training weapon or component resulting in occurrences whereby the possibility of detonation or radioactive contamination is increased, but which does not constitute an accident.

Radiation Hazard Card Handout

E M E R G E N C Y - THIS AREA PROBABLY CONTAINS RADIOACTIVE CONTAMINATION Follow my directions to the radiation control point where you will be given further instructions.

Note:

- 3" x 5" card
- White background
- Red lettering

T R A F F I C   C O N T R O L   I N S T R U C T I O N S

THIS ACCIDENT MAY HAVE CAUSED RADIOACTIVE CONTAMINATION IN THE LOCAL AREA. YOU ARE REQUESTED TO DETOUR AROUND THIS AREA. IF YOU PROCEED AT YOUR OWN RISK:

1. Keep all windows and vents closed.

2. Proceed without stopping.

3. Wash vehicle thoroughly at first opportunity.

Note:

3" x 5" card
White background
Red lettering

IV. Problems: None

V. Solutions: None

MANAGEMENT OF RADIATION ACCIDENTS

DF510

DF510, MANAGEMENT OF RADIATION ACCIDENTS

I. Reference and Discussion.

A. Reference: None

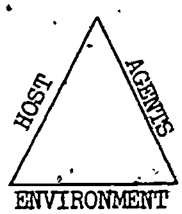
B. Discussion:

1. Radiation Accident.

The unexpected occurrence in a sequence of events which produces injury, death, radiation exposure, or property damage.

2. Radiation Incident.

The unexpected release or loss of control of radioactive material either sealed or unsealed to the environment.



4. Host

a. Conditions
b. Senses
c. Motor skills
d. Psychological
e. Stresses

Influenced by

a. Age - old and young
b. Illness and disease
c. Alcohol and drugs
d. Living conditions
e. Training

5. Environmental Factors.

a. Temperature
b. Humidity
c. Lighting
d. Housekeeping
e. Toxic material

6. Agents (radioactive material).

Identification of the agents is essential. It will influence all aspects of control and emergency situations.

7. Objectives of Incident Control Planning.

a. Prevention of the incident or accident.
b. Minimizing the effects of an incident or accident.
c. Controlling the incident or accident.
d. Restoration measures.

8. Incident Control Planning.

a. Preplanning in facility design.
b. Periodic review of techniques, equipment, and operations.
c. Review of all new proposals, techniques, and equipment.
d. Training and educational programs in all aspects of safety.

9. Minimizing the Effects of the Accident or Incident.

a. Lifesaving measures.

1. Equipment for lifesaving.
2. Maximum allowable exposure for lifesaving.

b. Evacuation plans.
c. Clear-cut organizational responsibilities.
d. Countermeasure to prevent large scale contamination of the environment.

10. Controlling the Incident or Accident.

a. Trained individuals with necessary instruments.
b. Accessory equipment.
c. Established communication system.
d. Up-to-date list of agencies which could provide assistance.

11. Restoration Measures.

a. Decontamination teams and equipment.
b. Disposal procedures.
c. Contamination guidelines.

NOT A VU-GRAPH

Reports Required by Federal Law - immediate, 24-hour, 30-day.

1. Loss or theft of source - immediate to NRC Regional Compliance Office by telephone or telegraph if the loss appears to the licensee that a substantial hazard may result to persons in unrestricted areas.

2. Follow-up report for loss or theft within 30 days of the initial report. Send to Director, Division of Compliance, USAEC, Washington, D. C. 20545, with a copy to the Director of the appropriate NRC Regional Compliance Office.

12. Report Information of 30-day Follow-up on Loss or Theft.

a. Description of the licensed material involved.
b. Description of the circumstances under which the loss or theft occurred.
c. Statement of disposition or probable disposition of licensed material involved.
d. Radiation exposure to individuals.
e. Recovery actions.
f. Preventive measures to eliminate other occurrences.

NOT A VU-GRAPH

Subsequent to filing the written report, the licensee shall report any substantive additional information which he may receive, within 30 days after he learns of such information.

Any report filed for the above listed reason shall be so prepared that names of individuals who may have received exposure to radiation are stated in a separate part of the report.

13. Immediate Notification.

a. Exposure.

(1) Whole body - 25 rems or more.
(2) Skin of whole body - 150 rems or more.
(3) Feet, ankles, hands or forearms - 375 rems or more.

b. Release of radioactive materials. Concentrations averaged over 24 hours which would exceed 5000 times limits in App B, Table II.

c. Loss of one working week of operating facility.
d. Damage in excess of $100,000.

14. Twenty-four Hour Notification.

a. Exposure.

(1) Whole body - 5 rems or more.
(2) Skin of whole body - 150 rems or more.
(3) Feet, ankles, hands or forearms - 75 rems or more.

b. Release of radioactive materials. Concentrations averaged over 24 hours which would exceed 500 times limits in App B, Table II.
c. Loss of one day or more of the operating facility.
d. Damage to property in excess of $1,000.

15. Thirty-day Report.

a. Each exposure to radiation or concentration in excess of any limits or license held.
b. Any incident for which notification is required.
c. Levels or concentrations in an unrestricted area in excess of ten times any applicable limits set forth.

NOT A VU-GRAPH

Report must contain:

a. Extent of exposure to persons to radiation or radioactive material.
b. Levels or concentrations of material involved.
c. Cause of the exposure, levels, or concentrations.
d. Corrective steps taken or planned to assure against a recurrence.

NOT A VU-GRAPH

If a licensee must submit a report on an individual to radiation or concentrations of radioactive material, the licensee shall also notify such individuals of the nature and extent of the exposure. The notice shall be in writing and shall contain the following statement:

"This report is furnished to you under the provisions of the NRC regulations entitled 'Standards for Protection Against Radiation' (10 CFR Part 20). You should preserve this report for future reference."

16. Army Regulations on Accident/Incident Reporting.

a. AR 385-40
b. AR 385-10
c. AR 385-14
d. AR 55-55
e. AR 700-64
f. AR 755-15
g. AR 40-14
h. AR 700-63
i. AR 700-52
j. AR 50-2,

k. Other regulations concerning release of accident information, fire, marine accidents, legal and other aspects are referenced in AR 385-40.

II. Lesson Objectives and Notes.

A. Objectives:

1. Define and explain radiation accidents and radiation incidents involving non-weapons radioactive material.

2. State the causes of accidents/incidents and explain each of these causes as to influencing factors.

3. State the guidelines for an emergency plan.

4. Make all accident reports required (both Federal and military).

5. As RPO, handle in a safe, expeditious, efficient manner, any radiation accident which may occur at the RPO's facility.

B. Notes:

III. Handouts: See attached handouts.

IV. Problems: None

V. Solutions: None

EXTRACT FROM NRC OPERATING HANDBOOK
STANDARDS FOR RADIATION PROTECTION

III. GUIDANCE FOR EMERGENCY EXPOSURE DURING RESCUE AND RECOVERY ACTIVITIES

A. Purpose.

The emergency action guidance promulgated in this part provides instructions and background information for use in determining appropriate actions concerning the rescue and recovery of persons and the protection of health and property during periods of emergency.

B. General Considerations.

1. The problem of controlling exposure to radiation during rescue and recovery actions is extremely complex. Performing rescue and recovery operations require the exercise of prompt judgment to take into account multiple hazards and alternate methods of accomplishment. Sound judgment and flexibility of action are crucial to the success of any type of emergency actions. Although the guiding principle is to minimize the risk of injury to those persons involved in the rescue and recovery activities, the control of radiation exposures should be consistent with the immediate objective of saving human life, the recovery of a deceased victim, and/or protecting of health and saving of property.*

2. To preclude the possibility of unnecessarily restricting action that may be necessary to save lives, these instructions do not establish a rigid upper limit of exposure but rather leave judgment up to persons in charge of emergency operations to determine the amount of exposures that should be permitted to perform the emergency mission.

3. The official in charge must carefully examine any proposed action involving further radiation exposure by weighing the risks of radiation results, actual or potential, against the benefits to be gained. Exposure probability, biological consequences related to dose, and the number of people involved are the essential elements to be evaluated in making a risk determination.

4. These instructions recognize that accident situations involving the saving of lives will require separate criteria from that of actions required to recover deceased victims or saving of property. In the latter instances, the amount of exposure expected to be received by persons should be controlled as much as possible within occupational limits.

*The determination as to whether radiation dosage received in emergency actions will be chargeable to the radiation exposure status of the persons will be made on an individual basis.

C. Field Office Managers in Accordance with Subsection 0524-034.

1. Shall review and approve emergency plans for rescue and recovery operations.

2. May authorize contractors to take all appropriate measures in emergency situations.

3. Normally shall not allow the recovery operation personnel to exceed the occupational exposure standards specified in part I and annex I of this appendix for the recovery of deceased victims; however, in special circumstances may approve a waiver of these limits.

D. Emergency Situations.

Specific dose criteria and judgment factors are set forth for the three categories of risk-benefit considerations, i.e., actions involving the saving of human life, the recovery of deceased victims, and the protection of health and property.

1. Saving of Human Life.

a. To preclude the possibility of unnecessarily restricting action that may be necessary to save lives, judgment shall be left to persons in charge of emergency operations to determine the amount of exposures that should be permitted to perform the emergency mission.

b. Attempts to rescue victims of a nuclear incident should be regarded in the same context as any other emergency action involving the rescue of victims, regardless of the type of hazard involved.

c. Where there is reasonable expectation that an individual is alive within the affected area, the course of action to be pursued should be determined by the person onsite having the emergency action responsibility.

d. The amount of exposure for this type of emergency action shall be determined by the person onsite having the emergency action responsibility. He should immediately evaluate the situation and establish the exposure limit for the rescue mission accordingly. His judgment should be based upon:

(1) Evaluation of the inherent risks by considering:

(a) The reliability of the prediction of radiation injury. This reliability cannot be any greater than reliability of the estimation of the dose. Therefore, consideration should be given to limits of error associated with the specific instruments and techniques used to estimate the dose rate. This is especially crucial when the estimated dose approximates 100 rems or more.

(b) The exposure expected in performing the action shall be weighed in terms of the effects of acute external whole body exposure and entry of radioactive material into the body.

(2) Current assessment of the degree and nature of the hazard, inherent risk from that hazard through appropriate mechanism such as the use of protective equipment, remote manipulation equipment, or similar means.

e. In the course of making a decision to perform the action, the risk to rescue personnel should be weighed against the probability of success of the rescue action.

f. Any rescue action that may involve substantial personal risk should be performed by volunteers, and each emergency worker shall be advised of the known or estimated extent of such risk prior to participation.

2. Recovery of Deceased Victims.

a. Accident situations involving recovery of deceased victims require criteria separate from those for saving lives. Since the element of time is no longer a critical factor, the recovery of deceased victims should be well planned. The amount of radiation exposure received by persons in recovery operations shall be controlled within existing occupational exposure guides.

b. In those situations where the bodies are located in areas inaccessible because of high direct radiation fields, and where the recovery mission would result in exposure in excess of occupational exposure standards contained in this part, special remote recovery devices should be used to retrieve the bodies.

c. In special circumstances where it is impossible to recover bodies without the entry of emergency workers into the area, the individual in charge of the recovery mission may determine it necessary to exceed the occupational exposure standards contained in this part. The planned exposures of an individual participating in the recovery should not exceed 12 rem total for the year or 5 (n-18) whichever is the more limiting.

3. Protection of Health and Property.

a. Where the risk (probability and magnitude) of the radiation hazard either bears significantly on the state of health of people or may result in loss of property, so that immediate remedial action is required, the following criteria should apply:

(1) When the person in charge of emergency action onsite deems it essential to reduce a hazard potential to acceptable levels or to prevent a substantial loss of property, a planned exposure up to but not to exceed 12 rem for the year or 5 (N-18) whichever is more limiting may be received by individuals participating in the operation.

However, the person in charge of emergency action at the incident scene may elect under special circumstances to waive these limits and permit volunteers to receive an exposure up to but not to exceed 25 rem.

(2) Where the potential risk of radiation hazard following the nuclear incident is such that life would be in jeopardy, or that there would be severe effects on health of the public or loss of property inimical to the public safety, the criteria for the saving of human life shall apply.

EXTRACT FROM NRC OPERATING HANDBOOK

NOTIFICATION, INVESTIGATION, AND REPORTING OF INCIDENTS REQUIRING IMMEDIATE NOTICE TO HEADQUARTERS

I. CATEGORIES OF INCIDENTS REQUIRING HEADQUARTERS ACTION

Incidents involving any of the following circumstances may require prompt notice to the public and NRC Committee on Atomic Energy and notice thereof should be made to Headquarters as soon as any become known.

A. Under NRC or Contractor Operations.

1. Radiation.

a. Exposure of the whole body of an individual to 25 rems or more of radiation, exposure of the skin of the whole body of an individual to 150 rems or more of radiation or exposure of the feet, ankles, hands or forearms of any individual to 375 rems or more of radiation;

b. Any unplanned release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 5,000 times the limits specified for such materials in appendix 0524, annex 1;

c. Any release of radioactive material offsite where it is believed any member of the general population may have received an exposure greater than than that set forth in appendix 0524, II;

d. Any accident in which an atomic or nuclear weapon (under the jurisdiction of NRC) is involved and where damage is inflicted to persons or private property;

e. Any notice that an individual has received an estimated 25 rems or more of external whole body radiation during a calendar year;

f. Any injury or industrial illness following cumulative or massive exposure to internal or external ionizing radiation which might reasonably be expected to have caused the illness or injury and when so diagnosed by a physician competent in nuclear medicine;

g. Allegations that persons previously employed by NRC or its contractors are disabled from injuries or diseases incurred as a result of radiation or exposure to toxic materials which are peculiar in kind or degree to atomic energy operations.

2. Injury or Death.

a. Any fatal or imminently fatal injury or illness of industrial origin associated with an NRC activity of an NRC or contractor employee or a member of the public in an accident or fire;

b. Any other injury or industrial illness of five or more persons in an NRC operation;

c. Allegations that persons previously employed by NRC or its contractors died from or were injured as a result of their duties in atomic energy operations.

3. Loss.

a. Estimated loss or damage to Government property amounting to $100,000 or more or estimated costs of $100,000 required for cleaning, renovating, replacing or rehabilitating structures, equipment, or property;

b. Any apparent loss of source or special nuclear material, when such apparent loss has been referred to the FBI for their information or investigation.

NOTE: The notification in the matter in item 3b may consist of a copy of the referral to the Federal Bureau of Investigation, which has primary investigative jurisdiction of such matters.

c. Any apparent loss or theft of byproduct source, or special nuclear material, other than that mentioned in items 3a or 3b above, in such quantities and under such circumstances that it is believed there may result a substantial hazard to the health and safety of individuals.

B. Public Interest.

1. Any incident of any kind which gives rise to an inquiry by members of the public or press, providing that after initial analysis by a field office, it is considered of sufficient importance to notify Headquarters.

2. Any incident of any kind which the field office manager believes to have public information significance.

3. Any offsite accident involving vehicles carrying NRC shipments of radioactive materials.

II. NOTIFICATION STANDARDS

A. As soon as sufficient information is obtained to indicate the general nature and extent of the incident, the responsible Headquarters supervising official shall be notified by telephone. This telephone notification should be made within a matter of hours if at all possible, even at the expense of lack of some of the details of the incident. A confirming teletype shall be sent as soon as possible giving whatever details are

available. This teletype shall include as addressees, the responsible Headquarters supervising official, appropriate programmatic division director, appropriate programmatic Assistant General Manager, the Divisons of Inspection, Operational Safety (in health and safety matters) and Public information. This teletype shall cover:

1. Whether a press release is contemplated or has been issued.

2. Whether all facts are known and no investigation is required.

B. The recipient of the original notice shall immediately notify the Divisions of Inspection. Operational Safety (in health and safety matters) and other interested Assistant General Managers, divisions and offices.

III. INVESTIGATION STANDARDS

A. General.

The investigation and analysis should be conducted to obtain information necessary to:

1. Determine nature and extent (including costs) of the incident.

2. Determine the causes of and responsibility for the incident.

3. Determine corrective action appropriate to minimize or preclude similar incidents.

4. Arrive at an informed estimate of amounts, probability and validity of claims against the Government.

5. Assist in the improvement of NRC policies, standards, and regulations and of operations thereunder.

6. Prepare a written report.

7. Determine that appropriate corrective action and follow-up are accomplished.

B. Standards for Selection of Investigators.

1. Designated investigator(s) (or teams) shall be selected to supply not only specialized competence in the subject area concerned, but also competence in investigative and report writing techniques.

2. NRC and contractor personnel employed in positions directly related to the operation or activity in which the incident has occurred may serve on an investigative committee but shall not constitute a majority of the team nor serve as the only investigator or as head of the investigative team.

3. NRC officials who initiate investigations shall:

   a. Appoint or approve investigator(s) or those who serve on the investigative team.

   b. Designate a full-time Government employee to conduct the investigation or to head the team where one is used.

C. Collection of Data.

1. Information shall be obtained from the best source, i.e., those persons involved in the incident, and those present at the time of the incident, along with personal observation on the part of the technically qualified investigator.

2. The following data should be obtained where applicable:

   a. Concerning the facility:

      (1) Contractor or facility involved and location of facility.

      (2) Area or room where the incident occurred or where the missing material was supposed to be.

      (3) Contract or other connection with the NRC.

      (4) Names and titles of persons involved.

   b. Concerning the incident:

      (1) Type of incident or occurrence.

      (2) Date, time, and circumstances.

      (3) What brought incident to attention.

      (4) Cause and responsibility for incident or occurrence.

      (5) Description of damage and/or loss, and action being taken to repair damage or prevent further damage and/or loss.

      (6) Cost; i.e., replacement cost of damaged items, or assigned dollar value of missing material.

   c. Concerning any injuries:

      (1) Extent of injuries.

(2) Action taken to care for injuries.

(3) Action taken to preclude further injuries.

d. Concerning the possibility of a claim against the Government:

(1) What possibilities for claims against the Government were created by the incident or loss. Describe the possible claims.

(2) What information is available to refute or mitigate the claims.

e. Concerning corrective action:

(1) If the incident or loss resulted from a failure to follow procedures, laws, or regulations, what action is warranted or is being taken to ensure future compliance.

(2) If the incident or loss resulted from lack of or inadequate procedures, what action is being taken to correct the deficiency.

3. Concerning the loss of source and special nuclear material the following additional information must be obtained:

a. If missing material, description, chemical and physical form, quantity, etc.

b. Classification of missing material.

c. If missing material, relation of missing quantity to total batch or inventory from which missed.

d. If loss was not immediately noted, when and under what circumstances was it noted.

e. For missing material, when and how is the material last known to have been on hand.

f. What steps have been or are being taken to locate the missing material.

g. What are the possible mechanisms by which the material could have left the facility. For each mechanism what evidence exists that this was or was not the loss mechanism, and what practicable possibilities exist for further investigation.

h. What is the most probable loss mechanism, based on present information.

4. In cases involving overexposure to ionizing radiation the following additional information must be obtained:

a. Personal information:

(1) Date of birth.

(2) Place of birth.

(3) Sex.

(4) Social Security number.

b. Occupational information:

(1) Name and address of employer.

(2) Position title of employee.

(3) Area of facility employed in during period of exposure.

c. Radiation exposure information:

(1) Approximate dates for period during which exposure was accumulated.

(2) Total estimated radiation dose in rems.

(3) Type of radiation involved (e.g., X-ray, gamma, neutron, electrons, positrons, heavy particles).

(4) Manner in which personnel radiation dose measurements were made (e.g., film badge, dosimeter, survey meter).

(5) Procedures used for converting units of measurement to REM dose values (e.g., survey meter reading in r times RBE of ______ for ______ radiation; ______ neutron tracks per square centimeter equals ______ rem dose; density of duPont type 502 film in terms of r times RBE of ______ for ______ radiation).

(6) Extent to which the permissible accumulated radiation dose has been exceeded.

IV. REPORTING STANDARDS

A. Investigative reports shall be written in two separate parts.

1. The first part shall contain an orderly presentation of the established facts relative to the incident.

2. The second part shall contain a clear statement of the conclusions reached and/or the recommendations which will make effective disposition of all phases of the case. The conclusions must be supported by the facts developed. Each recommendation should be stated so as to clearly identify the action(s) required to carry it out.

Conclusions and/or recommendations shall be marked "Official Use Only" and shall be a separate memorandum signed by the chairman of the committee or the investigator.

B. Investigative reports are submitted initially to the NRC officials responsible for ordering the investigations. If the final report cannot be submitted within 30 days, the Headquarters supervising official and the Division of Operational Safety in health and safety matters shall be notified as to the reason for the delay and the anticipated date of submittal. A record will be maintained of management actions taken on investigation findings and recommendations.

C. Reports will only be distributed to those listed in the chapter and no further distribution of such reports shall be made except with permission of the Headquarters supervising official in consultation with the appropriate programmatic Assistant General Manager, and/or appropriate programmatic division director.

V. PROCEDURE TO BE FOLLOWED WHEN INVESTIGATION IS TO BE CONDUCTED BY HEADQUARTERS

Except as otherwise prescribed by the Commission, investigations of incidents (as defined in section 0703-5) required by the Commission or by the General Manager to be conducted by Headquarters will be conducted by the Director, Division of Inspection, as provided in this part V.

A. Investigations by the Director, Division of Inspection.

In conducting investigations, as required by subsection 0703-033 d, the Director, Division of Inspection shall:

1. Direct the Assistant Director for Investigations, Division of Inspection, to collect and report to him on all facts concerning the incident in accordance with the standards set forth in part III.

2. In addition, when appropriate, designate one or more technical experts to collect, evaluate, and report to him on relevant technical data. Such designated persons shall:

   a. Take immediate action to collect technical data that would not be available in case of delay such as information concerning decaying short half-life material.

b. Make arrangements for laboratory or other facilities needed to analyze technical data that has been collected.

c. Appropriately coordinate their efforts with the staff of the Assistant Director for Investigations assigned to the incident.

3. In matters relating to incidents in operations under the jurisdiction of a Field Office Manager:

a. Through the cooperation of the Field Officer Manager, control access to the site of the incident by excluding all persons except those whose presence is essential to investigative activities or to necessary operations.

b. Assure that the investigation will not interfere with emergency operations of the Field Office Manager resulting from the incident.

c. Secure administrative and other support from the Field Office Manager.

d. Assure that the Field Officer Manager is not relieved of any of his operational responsibility through actions of representatives of the Division of Inspection or of a Board of Investigation (see B below).

4. In matters relating to incidents in licensee operations, assure that the investigation activity will be conducted in accordance with the direction of the Commission and in such a manner as will not interfere with the responsibilities of the Director of Regulation.

5. Upon completion of the investigation, submit a detailed, factual report to the Commission through the General Manager or the Director of Regulation, as appropriate. The report shall be in the form prescribed by part IV A. The report shall not contain conclusions as to legal matters, such as negligence or questions of liability on the part of persons or organizations involved. Questions as to the legal implications of conclusions in the report shall as appropriate, be referred to the Office of the General Counsel for advice.

B. Boards of Investigation.

1. If the Director, Division of Inspection, believes that his investigation of an incident should be supplemented by the expert opinion and advice of a Board of Investigation, the Director, Division of Inspection, will constitute such a Board, with advice from the Director of Regulation in regulatory matters, and the Director, Division of Operational Safety, in matters under the jurisdiction of the General Manager.

2. The Director, Division of Inspection, shall request the General Counsel to appoint a Counsel to the Board of Investigation who shall attend the meetings of the Board and advise and assist it.

3. The members of the Board shall be selected from highly qualified experts in the field of the incident under investigation who are employees of the NRC or its contractors and shall be composed as follows:

   a. There shall be no less than three nor more than five members.

   b. One or more members shall be NRC employees and a full time NRC employee shall be appointed Chairman of the Board of Investigation.

4. The Director, Division of Inspection, and Manager of Field Office, through the Director, Division of Inspection, shall assure that the Board of Investigation receives all relevant information concerning or resulting from the investigative efforts of Headquarters and Field Office staff, respectively, with respect to the particular incident under investigation.

5. The Board of Investigation may question witnesses and examine documents, equipment, facilities, and sites relevant to the incident.

6. If, after reviewing all information furnished and making such inquiries as it deems necessary, the Board of Investigation determines that additional information is needed, the Director, Division of Inspection, will be requested to obtain and furnish such information.

7. After completing its review and prior to preparation of its written report, the Board of Investigation shall consult with the Director, Division of Inspection, concerning the results of its investigation to determine if any further investigation by the Board is necessary or desirable.

8. Thereafter, if it appears that no further review or action by the Board of Investigation is necessary or appropriate, the Board shall prepare a detailed, factual report to the Director, Division of Inspection, setting forth the results of its investigation. The report shall be in the form prescribed by part IV.A. It shall not contain conclusions as to legal matters, such as negligence or questions of liability on the part of persons or organizations involved. It shall be referred to Counsel to the Board for review and advice as to legal implications prior to submission to the Director, Division of Inspection.

EXTRACTS FROM AR 55-55

Paragraph 12.

Accident/Incident Control and Reporting.

a. Transportation. Transportation as used in this regulation with respect to accident/incident reporting will include all events for the period of time from the acceptance of the item for shipment until delivery to and acceptance by the consignee. For information in connection with accident/incident reporting, see AR 385-40. Reporting of packaging and handling deficiencies are prescribed in AR 700-58.

b. Action to be taken in case of an accident involving radioactive or fissile materials (App C): The senior person present will -

(1) If radioactive materials are exposed or if contamination is suspected to exist, establish an exclusion area to prevent the general public from exposure to radiation or contamination. Accept local assistance if required. The exclusion area will be maintained until the appropriate radiological team certifies that the danger is past.

(2) Take such other emergency action as the situation required (rescue operations, firefighting, etc.).

(3) Notify the nearest military installation and request immediate assistance, giving pertinent information as follows:

(a) Location and nature of accident.

(b) Emergency procedures initiated.

(c) Type materials involved and help required.

(d) A request that shipping installation be notified at earliest possible time.

(4) Notify the Deputy Chief of Staff for Logistics, ATTN: LOG/TR-TEB, Department of the Army, during normal duty hours and the DSLOG Duty Officer at all other times, giving such details as are available.

(5) Prepare an on-the-scene report, which will detail all pertinent factors contributing to the accident and the emergency measures initiated to protect personnel and property. This report will be submitted within 24 hours to the safety office of the shipping installation, with copies to the Deputy Chief of Staff for Logistics, ATTN: LOG/TR-TEB, Department of the Army, Washington, D.C. 20310, and to the safety officer of the Army installation providing assistance. If military vehicles are involved, this report will be made in addition to the reports required by AR 385-40.

c. Action to be taken in case of an incident involving radioactive or fissile materials (App C). The senior person present will -

(1) Take the necessary precautionary measures to protect personnel and property and to prevent development of the incident into accident.

(2) Notify the nearest military installation to request assistance if required.

(3) Notify the shipping installation and request instructions to safely complete mission.

(4) Prepare an on-the-scene report which will detail the incident emergency measures taken, and assistance requested and rendered to reduce the incident.

(5) Report incidents to the safety director of the shipping installation within 24 hours of the event. The safety officer will submit a written report within 5 days to the Deputy Chief of Staff for Logistics, ATTN: LOG/TR-TEB, Department of the Army, Washington, D.C. 20310, and to such other command levels as required. This written report will detail the incident emergency actions taken and the assistance requested and rendered to reduce the incident.

d. Reports indicated in b and c above will not be given to local police officers or to representatives of the press. The senior man present will make such answers to the local police as are required by law to complete their report but will not discuss the nature of the lading except to indicate the need for the required safety measures taken.

e. Relations with the press and release of information to the public concerning nuclear accidents and incidents will be governed by the provisions of AR 360-43.

APPENDIX A

SAFETY

1. Definitions. Alpha, REMT, and RADCON Teams are defined in AR 50-5.

2. General. Nuclear and radioactive materials, if involved in a transportation accident, may have the packaging so damaged as to cause the contamination of an area and become a personnel hazard. In case of a serious accident involving nuclear or radioactive materials, the ranking person (guard, courier, escort, or transportation personnel) accompanying the shipment will take immediate steps to clear the area and request assistance.

3. Action at site.

a. The responsible person at the scene, after taking the necessary emergency action required to protect personnel and property, will report by telephone to the nearest military or NRC installation and, if needed, he will request aid. He will also request that the Army area be notified. If there is no nearby military or NRC installation from which help can be secured, a telephone report and request for aid will be made to the headquarters of the Army area in which the accident/incident occurred. Appropriate telephone numbers to call for assistance will be included in the written instructions provided the driver or escort commander.

b. Local police authorities may be called upon to assist in the control of the area and to exclude the public to prevent possible radiation exposures until authorized Army control can be established.

c. In the event the shipment is unescorted, the driver or conductor will be instructed to obtain assistance at the scene to maintain exclusion of the area until such time as other assistance is available. In event of a fire, contact local fire department.

4. Interagency radiological assistance.

a. The Federal Interagency Radiological Assistance Plans, the principal proponents of which are the Department of Defense and the Nuclear Regulatory Commission, provides the procedures and the resources for the expeditious supply of effective radiological assistance to anyone requesting it in case of a radiological accident/incident. This plan is administered for the military services through the Joint Nuclear Accident Coordinating Center (JNACC) located at Sandia Base, Albuquerque, New Mexico.

b. Any military or NRC installation receiving a request for radiological aid will contact, in accordance with existing plan, the appropriate higher headquarters to initiate action under the JNACC procedures.

c. In the event several individuals have become contaminated or the contamination on an individual is not localized to a small portion of the body, the following decontamination procedure will be used:

(1) Place individual under a tepid shower.

(2) Using a mild toilet soap; individual will cover entire body with lather.

(3) While still covered with lather, individual will step out of shower.

(4) An assistant will sprinkle a heavy coat of mild soapflakes all over lathered individual. (Purpose of lather is to cause soapflakes to adhere to person.)

(5) Using his hands, the contaminated individual will rub the soapflakes on his body into a paste.

(6) Individual will then return to shower and attempt to rinse soap off of his person by starting at the top and working his way down.

NOTE: It will be necessary for individual to rub body surfaces with his hands while rinsing in order to remove soap paste. Soap paste will remain on those areas which have not been thoroughly washed. Although a soft cloth may be used, a brush may not. Particular attention should be given hairy portions of the body.

(7) When the individual has rinsed himself to the point that he no longer feels slimy and while still under shower, he will be examined by an assistant for traces of soap. The presence of soap will indicate which areas of the body have not been decontaminated.

(8) After removing all traces of soap, individual will leave the shower and dry himself.

(9) After drying off, individual will be monitored. If individual is still generally contaminated, procedures will be repeated.

APPENDIX B

EMERGENCY PROCEDURES TO FOLLOW IN ACCIDENT/INCIDENT SITUATIONS

1. Probable emergencies. A radiological emergency is any unplanned event which could adversely affect the safe movement of radioactive materials. A severe emergency could result from collision, fire, explosion, or loss of control, e.g., theft, spillage, leakage, and misplacement of the cargo. Overexposure and contamination of personnel and property could be the end result.

2. General guidance. The prime objective of emergency action is the protection of personnel from the hazards of radiation and contamination. Second consideration should be the confinement of the contamination to the local area of the accident. Although no set of rules are available to handle every conceivable incident, the proper adaptation of the more specific guidance furnished below will minimize the danger to personnel and property. In the event there is reason to believe that personnel may have been contaminated and/or overexposed, efforts will be directed toward locating those persons so that any necessary decontamination and medical assistance may be furnished. It may be necessary to obtain the aid of local authorities to locate personnel along the shipping route who may have been contaminated or overexposed.

3. Emergencies involving collision, fire, explosion, leakage, or spills.

a. Danger. Personnel overexposure could result from increased dose rates. Contamination of property and equipment could occur.

b. Immediate action.

(1) Minimize emergency, if possible. Extinguish fire with dry-chemical fire extinguisher.

(2) Utilize on-site assistance in order to:

(a) Establish exclusion area. Increase distances shown on DD Form 836 to keep personnel out of smoke, leakage, spillage or mists.

(b) Render first aid. Inform medical personnel that injured may be contaminated.

(c) Call for necessary assistance from local fire, police or public health departments and nearest military or NRC installation.

(d) Control personnel who may be contaminated.

1. Obtain names and addresses.

2. Discourage smoking, eating, drinking, and leaving until monitoring and decontamination assistance is available.

(e) Localize contamination. Example: Leakage and spillage on highway can be removed by sweeping or shovelling contaminated material into a suitable container and holding for disposal. If liquid has been spilled the contamination may be contained by means of dirt, cloth, sawdust, or other absorbent material. Dusts can be settled by means of a fine water spray.

c. Subsequent action:

(1) Monitor and decontaminate personnel, if necessary. See paragraph 5 of this appendix for guidance on decontamination of personnel. Assistance of local health department, civil defense, nearest CBR team, or other RAD Safety Team may be necessary.

(2) Monitor and decontaminate property. (Same assistance as (1) above may be necessary.) Reduce exclusion area to bare minimum.

(3) Document the emergency.

4. Procedures in case of theft or loss.

a. Notify Army area headquarters.

b. Notify consignor.

c. Notify FBI and local police officials if theft is suspected.

d. Attempt to recover in case of loss.

5. Decontamination of personnel.

a. If packages were undamaged, contamination is unlikely. However, radiac instruments are necessary to verify the presence or absence of contamination. For beta-gamma materials, this requires a Geiger Mueller type instrument capable of distinguishing dose rates between zero and 0.2 milliroentgen per hour. For alpha-emitting materials, an instrument capable of detecting 500 alpha particles per minute per 16 square inches is required. Further, it should be noted that alpha radiation cannot be detected from moist or wet surfaces.

b. Thorough washing with nonabrasive soap and lukewarm water is the best general method of decontamination of the hands and other parts of the body, regardless of contaminant. If the contaminant is localized, it is often more practical to mark off the affected area and cleanse with swabs, rather than risk the danger of spreading the contaminant by general washing.

CAUTION: Organic solvents must be avoided as decontaminating agents because they may increase the probability of the radioactive materials' penetrating through the pores of the skin. Special attention must be given to the areas between the fingers and around the nails; also, the outer edges of the hands are readily contaminated and often neglected in the washing.

c. In the event several individuals have become contaminated or the contamination on an individual is not localized to a small portion of the body, the following decontamination procedure will be used:

(1) Place individual under a tepid shower.

(2) Using a mild toilet soap, individual will cover entire body with lather.

(3) While still covered with lather, individual will step out of shower.

(4) An assistant will sprinkle a heavy coat of mild soapflakes all over lathered individual. (Purpose of lather is to cause soapflakes to adhere to person.)

(5) Using his hands, the contaminated individual will rub the soapflakes on his body into a paste.

(6) Individual will then return to shower and attempt to rinse soap off of his person by starting at the top and working his way down.

NOTE: It will be necessary for individual to rub body surfaces with his hands while rinsing in order to remove soap paste. Soap paste will remain on those areas which have not been thoroughly washed. Although a soft cloth may be used, a brush may not. Particular attention should be given hairy portions of the body.

(7) When the individual has rinsed himself to the point that he no longer feels slimy and while still under shower, he will be examined by an assistant for traces of soap. The presence of soap will indicate which areas of the body have not been decontaminated.

(8) After removing all traces of soap, individual will leave the shower and dry himself.

(9) After drying off, individual will be monitored. If individual is still generally contaminated, procedures will be repeated.

RADIOACTIVE CONTAMINATION

At the laboratory located on your installation, a chemist has received a glass ampoule containing 1.27 curies of elemental sulfur-35 dissolved in 15 cc of benzene. This material was received in a heat-sealed all glass ampoule surrounded by packing material. Prior to opening it, the ampoule was chilled in an ice bath inside of two concentric containers. The ampoule was scored with a carborundum chip but could not be snapped open. Before it could be scored again, it exploded shattering both containing vessels and severely contaminating the operator. The operator received minor cuts on his hands from glass that penetrated his rubber gloves. There were also superficial cuts on his face around but not within the area protected by his safety glasses. His uniform and the exposed areas of his face were highly contaminated. He discarded his uniform, changed to clean clothes, and left his laboratory which was then sealed.

Describe the further handling of this situation.

INCIDENT INVOLVING A RADIOGRAPHIC SOURCE

A contractor on your installation is doing radiographic testing of some equipment. A radiographer is using a new 10 curie Co-60 remote radiography source to radiograph some pipes in a power plant under construction. From a shielded location he is cranking the source back to the source container when it sticks and will not return. He pulls and jerks the source;he finds that it has become disconnected and has dropped on the floor. He becomes excited and leaves the scene to get help.

There are 10 men, pipe fitters, assistants and welders working in the building. The radiographer says that he returned in approximately 20 minutes and you are there 5 minutes after this.

What is your course of operation?

Information:

Co-60 - 1 curie = 13.7 rad/hr @ 1 foot

Half-life = 5.2 years

Co-60 gives off a 1.33 Mev gamma and a 1.17 Mev gamma

RADIATION ACCIDENT INVOLVING RADIATION GAUGES

A fire occurred in a two story supply facility on your installation. Involved in this facility was a process control system using 5 beta gauges containing radioactive Strontium-90. You, as RPO, are on the emergency team called in to advise on proper actions to take while fighting the fire and subsequent cleanup.

Sources were contained on two floors of the building and each source employed the standard SIA source capsule whose strength was 10 - 12 millicuries of ^{90}Sr. The source capsule model SIA is made of stainless steel. The front window, which is copper braised to the body, has a thickness of 1.5 mil. The radioactivity is deposited on a ceramic disk covered with a silicate. The disk is placed in the capsule "hot" end adjacent to the thin window and the threaded plug is inserted using a silver bearing solder which has a melting point of 430° F.

The source housing is essentially a small cast aluminum box which is used to house the source and has appropriate control devices.

Describe how you would handle such a situation.

Describe the proper precautions to take while fighting the fire and during cleanup operations.

RADIOISOTOPE LABORATORY INCIDENT - IODINE-131

As RPO, you receive a call from the diagnostic radioisotope laboratory at the local military hospital. The laboratory staff consists of a radiologist and a technician. The laboratory is cleaned by the regular housekeeping staff of the hospital on Tuesday and Thursday nights. The 12 p.m. to 8 a.m. shift customarily performs these cleaning duties.

The radiologist has been working with 10 millicuries of liquid Iodine-131 in a beaker on the stainless steel laboratory bench. On Tuesday evening before leaving work, the technician places a tight Saran wrap cover on the beaker to prevent evaporation. Upon entering the laboratory at 7:50 a.m. on Wednesday morning, the technician discovers the beaker lying broken in the waste basket under a desk amid paper desk trash. There is no sign of the solution except for the white crystalline residue on the broken glass. The floor seems clean of glass fragments. On the desk was a note from the night housekeeping supervisor explaining that the janitor on duty had knocked the beaker off the bench while cleaning the laboratory and had cleaned up the spill himself. The radiologist immediately telephoned you.

a. In logical sequence, outline the procedures you would take in handling the situation.

b. What changes should be initiated in laboratory techniques and management to obviate further incidents of this kind?

RADIOISOTOPE SPILL

At approximately 4 A.M., a strong gust of wind blew a carton of radioisotopes off an airline freight truck in a passenger walkway on the west concourse of the airport. The package dropped in front of the truck in such a position that the right front tire of the truck ran over the carton containing the radioisotopes. Mr. Brown, driver of the truck, placed the damaged carton back on the truck without noticing the label, and was therefore unaware of the nature of the contents, even though the carton did carry a radioactivity danger warning sign.

The package was a Blank Laboratories, Oak Ridge, Tennessee, standard cardboard shipping carton enclosing five metal radioisotope containers. The shipment consisted of:

Three containers, Orioiodide, Iodine-131 - 5 millicuries each; one container, Chromic Radiophosphate sterile Phosphorus 32 - 10 millicuries, and one container, Sodium Iodide sterile Iodine-131 - 10 millicuries.

At approximately 6:30 a.m., Mr. Adams, airline cargo service representative, noticed the radioactive materials label and realized the nature of the accident. At about 7:20 a.m., he telephoned advising the local military installation and you, as RPO, were told of the accident and that the contents of the carton were crushed and leaking. Four airlines personnel had come in contact with the package in addition to Mr. Adams and Mr. Brown, the driver of the truck. Mr. Brown was nauseated and vomited. The whole group was emotionally upset. None of the others had been observed to have any physical symptoms.

If you thought to ask Mr. Adams how many people might have been exposed to contamination from walking across or through the area of the original spill in the passenger walkway, he would have told you he did not know how many hundreds of people might have walked through the area. Since the area had not been roped off, hundreds of people actually had walked through.

If you had asked Mr. Adams what had been done with the carton after the accident occurred and if any other employees might have been exposed, he would have told you that Mr. Brown, the truck driver, had picked the carton up, put it back on his truck, taken it to the airport terminal building and put it down in an airfreight room. In addition, at this time of the morning, there were many employees of the airfreight line and other airport terminal employees coming and going.

Outline an appropriate course of action including environmental control procedures. If the amount of activity were two or threefold greater, how would this alter your course of action?

DF510.6

RADIATION ACCIDENT INVOLVING LOCAL ASSISTANTS

You are the Radiological Safety Officer at a military installation near a university located in a community of approximately 35,000 people.

The installation Provost Marshal received a call from the local police requesting assistance at an accident. There is a fire in a small independent radiological laboratory on the outskirts of town. The Provost Marshal informs the installation CO and he directs you to render all possible assistance.

The laboratory is a two-man operation owned by two former university professors who have gone into business for themselves and they have been doing radiological nuclide analysis, instrumentation calibration, and some industrial radiography.

The reason for the call was that one of the policemen noticed a radioactive material sign on a beaker. The policeman also noticed that only one of the operators can be located, but he is in an unconscious state and cannot answer any questions.

The policemen would like for you to come to the site and tell them if there is a problem at the laboratory and what can be done to minimize it.

You organize a five-man team and proceed to the site. When you arrive, the policemen are present but the medical emergency people have not arrived.

a. Outline the approach you should use, in the sequency of occurrence.

b. What information is necessary to protect the general public and to give the policemen a complete picture of the situation?

c. What decontamination, if any, should be taken?

RADIATION ACCIDENT INVOLVING A LABORATORY SPILL OF AN ALPHA EMITTER

You are the chemical officer at a large military installation involved in research and development work. There is a large laboratory located on this installation with a regularly assigned health physics officer. This health physics officer is away from the installation for a 4-week period attending a training course at Oak Ridge, Tennessee. You, as a radiological safety trained individual, have been detailed to fill in for this individual until his return.

The laboratory is made up of a series of stainless steel lined rooms opening on a center hallway. Each room has a separate independent ventilation system. At about 10:00 o'clock one morning, two technicians, a lieutenant, and a specialist started working on a project in which they used a dry thorium radioactive material. There was a health physics (EM) monitor present during the operation.

At lunchtime, the three individuals washed their hands and were monitored out of the lab using a hand monitor. They all went to lunch. After lunch, the health physics monitor discovers contamination on the bench in the lab and upon further investigation, contamination on the floor and out in the hallway is found.

An immediate call was placed to the HPO office and a man on duty responded with a beta-gamma instrument. You arrive and take the proper instruments to the laboratory. About this time, the lieutenant returns from lunch and you monitor him, finding contamination on his head, hands, and uniform.

In the following questioning of these three individuals, the EM monitor went to the local messhall, ate lunch, and returned directly to work; the enlisted technician went to his home, on post, ate lunch and returned directly to work; the lieutenant went to the Officer's Club, where he cashed a check, then went to the BOQ, where he fixed a sandwich for lunch. He ate the sandwich, drank a glass of milk, and laid on his bed while he read the morning newspaper. He then returned to work.

a. Outline your course of action as to the contamination in the laboratory.

b. Outline your course of action on outside contamination.

c. What type of alert, if any, should be issued to the post?

RADIATION ACCIDENT INVOLVING
AN ESCORTED SHIPMENT OF RADIOACTIVE MATERIAL

You are the RPO at a Government installation located near a major through highway. At 10:00 o'clock one morning you receive a call from the State Highway Patrol stating that a truck carrying a military shipment of radioactive material has caught fire a few miles from your installation. The driver of the truck has written instructions to contact the nearest military installation in case of an accident. The patrolman requests immediate assistance. A hurried call to the installation operations office gives you clearance to proceed. You immediately organize your staff and proceed to the scene.

The fire was first detected by the truck driver when smoke was observed emanating from the trailer. The truck was immediately halted and the tractor uncoupled, while the local fire department was summoned. Fire extinguishers from the vehicle and other trucks who stopped to assist were used to combat the blaze. The local fire department responded promptly, and, with their aid, the blaze was extinguished in approximately 15 minutes.

Part of the cargo was a gasoline-powered generator. While it could not be determined that this was the source, the probability is that a spark could have originated from the starter battery and started the fire.

a. What are your immediate actions?

b. What control should be initiated and what assistance may be needed?

RADIATION ACCIDENT INVOLVING A TRUCK SHIPMENT OF SOURCE MATERIAL

In your capacity as RPO, you receive a call for the local highway patrol on an accident which has occurred on a major highway near your installation. The request has been cleared through the installation CO and he has directed you to render all assistance possible.

The accident involved the collapse of a trailer due to structural failure, though the load was within the rated weight limits. The trailer carried 24 boxes of normal uranium slugs, weighing 37,000 pounds, and upon collapse of the trailer, the truck jackknifed into a ditch. Twelve wooden boxes of slugs were thrown on the road, five boxes broke open, and the slugs were scattered on both sides of the road.

The highway patrol has kept the traffic moving, otherwise they have sealed off the area.

a. What are your immediate instructions to the highway patrol officer?

b. What actions will you take when you arrive on the site?

DF510.10

RADIATION INCIDENT INVOLVING CONTAMINATION OF LOCALLY USED EQUIPMENT

In your routine duties as RPO, you have members of your organization pick up and move contaminated equipment to a safe storage area. Some of the contaminated equipment was packaged and monitored and then placed in a Government-owned pickup truck for onsite transport to the storage area to be made on the following day. A rainstorm during the night submerged the package in water, and it was, in turn, penetrated by the water. During transport of the package the following day, the water leaked from the package, contaminating the truck bed and chassis.

a. What is your course of action?

b. What corrective measures do you recommend to prevent a recurrence of this incident?

DF510.11

RADIATION ACCIDENT INVOLVING
AIR SHIPMENT OF RADIOISOTOPES - Ca-45

In a routine transfer of packages received at a local air terminal, one of the packages fell from the truck as it was being driven across the runway to another building for transshipment. As the package lay on the runway, it was run over by a commercial aircraft taking off on a routine flight to a neighboring state. The freight official discovered the package lying on the runway and called the fire department located at the airport. The package was picked up by the firemen and transferred to a remote building on the airport grounds. This transfer was accomplished by use of a shovel and a large wooden box, obtained from the freight office. The label on the outside of the package states that 118 millicuries of Ca-45 is in the package.

A call is placed to your installation requesting assistance and you, as RPO, are to respond.

a. What instructions should be given to the crew at the building containing the package prior to your arrival?

b. What procedures should be followed upon your arrival?

DF510.12

RADIATION ACCIDENT INVOLVING
A TRUCK SHIPMENT OF WASTE MATERIAL

During a routine shipment of (animal experiments) waste to a burial site, the tractor-trailer stalled at a local filling station. At that time, leakage and odor were noticed coming from the truck, and the military installation near the scene was called.

You, as RPO, are directed to investigate and to render all assistance possible.

Upon arrival at the scene, it is determined that one of the 23 drums involved has ruptured due to internal pressure en route. You monitor the material which has leaked from the truck and determine the radiation to be low level gamma only and the reading on this material is 1 mr/hr.

At this time representatives of the local newspaper arrive and request a statement from you.

a. What actions are necessary to control the contamination problem?

b. What type statement should you release to the newspaper?

RADIATION ACCIDENT INVOLVING OLD CONTAMINATED EQUIPMENT

You have been recently assigned the duties of RPO for your installation. You have a staff of four technicians working for you with the maximum amount of service in these jobs being only 18 months.

You receive a call from a medical warehouse supervisor requesting assistance. One of his men found in an old storage warehouse some items under a tarp which were marked with a radioactive warning sign. He immediately left the warehouse and reported to his supervisor, who, in turn, called you.

You get two of your staff, gather the proper instruments, and proceed to the scene. Upon arrival, one of your staff monitors the warehouseman and finds no contamination. Further investigation of the warehouse reveals low level beta-gamma (2 mrad/hr) contamination on the floor near a set of remote manipulator arms. The arms are contaminated with a beta-gamma emitter with readings of up to 20 mrad/hr on contact.

You question the supervisor and learn that no equipment has been removed or placed into this particular warehouse since he has worked in this area (approximately 7 years). No one else has any knowledge of these items. All records of storage have been retired or destroyed. You are able to locate the property holder as being an agency on the installation. From this agency you learn the items were stored approximately 10 - 12 years previously and the contamination is probably Cobalt-60.

a. What are your future actions regarding the contaminated equipment and the warehouse?

b. What action should be accomplished as far as documenting the time and type of contamination?

c. What precautions should be adopted to prevent future occurrences?

RADIATION ACCIDENT INVOLVING
A TRUCK SHIPMENT OF SOURCE MATERIALS

A semitrailer containing drums of uranium chips (metallic) was parked at your installation motor pool on Friday noon to be moved to its ultimate destination on the following Monday morning. During a routine inspection by a motor pool guard in the early evening, the trailer was found to be secure. On repassing the trailer 2 or 3 minutes later, the guard noted that the trailer had burst into flames. The blaze was extinguished by the local fire department. At this point, you are contacted and, in turn, call your assistants who respond, bringing anti-contamination clothing and various types of radiacmeters.

Upon arrival, you find the fire has damaged the trailer (privately owned) including destruction of interior body paneling, four tires, tarpaulin, one-third of the flooring, and break and light systems. Examination of the drums containing the uranium chips reveals that lids are off several drums as if by explosion. You are able to get the bills of lading from the tractor cab.

a. What are your immediate actions to control the scene? No emergency crew has left as of this time.

b. What are your actions toward the cargo of the truck?

DF510.16

RADIATION INCIDENT INVOLVING STUDENT CONTAMINATION OF LABORATORY

You are the Radiation Protection Officer at an installation involved in training of individuals using radioactive material.

In a routine class using Gold-198, students must perform decontamination of radiation contaminated plates. This exercise requires the students to complete the operations required, monitor this area, and be monitored out of the laboratory. At the completion of the exercise, these functions were done and the students were released.

The safety officer during the operation checked the area and found contamination on some student work benches. Your office was notified and further checked by your staff reveals heavy contamination of several spots on the floor and lighter contamination on the work bench. Evidence of contamination is discovered in the hallway outside the laboratory. All instructors are monitored and found to be clean. It is now 1700 hours.

a. What is your course of action?

b. What modification would you recommend to eliminate future occurrences?

RADIATION ACCIDENT INVOLVING A LEAKING SHIPMENT OF RADIOISOTOPES

A radioisotope shipment of Calcium-45 is received at your installation. In accordance with your local SOP, members of your staff monitor and wipe test the external surface of the package. No evidence of contamination is found so the package is turned over to the user for unpackaging and ultimate use as outlined in the SOP.

Two members of the user agency, a lieutenant and a specialist, unpack the radioisotopes. They find the glass vial in the package to be completely empty and the absorbent material to be damp. The materials are placed in a radiation hood equipped with a positive displacement filter and a negative airflow. The two men remove the rubber gloves, wash their hands, and monitor out of the preparation laboratory.

Several days later, the specialist and a civilian employee are using the same room to contaminate disks for a class in determination of unknown radioisotopes. The front part of the hood is in use and the operation is completed. In accordance with the SOP, the hands and feet of the civilian are monitored. Contamination is found on the heel of one shoe.

Your office is immediately notified and a check reveals contamination on several spots on the floor in front of the hood and contamination leading out of the doorway into the hall.

a. What are your immediate actions?

b. What areas should be checked?

c. What actions should be taken to prevent recurrence?

COMPUTATIONAL PROCEDURES
IN PHYSICAL SCIENCES

DF540, Computational Procedures in Physical Sciences

I. Reference: None.

II. Lesson Plan Outline: None.

III. Handouts: None.

IV. Problems:

Class and Home Study Problems.

1. What radioactive materials are always present in the atmosphere? What is their origin?

2. A sample was taken of airborne particulate radioactive contamination. Four hours after the sampling was stopped, it measured 53,800 cpm. Twenty hours later (after the first count) the sample measured 45,200 cpm. The background count was 26 cpm. What is the number of counts which may be attributed to long-lived isotopes?

3. A long-lived airborne contaminant measured 20,000 cpm. The sample was collected for 3 hours using a sampler with a flow of 20 cpm. The combined efficiency of the sampler and detector was 10%. What is the concentration in µCi/ml of the contaminant?

4. If the above contaminant is insoluble scandium-46, is this concentration greater than the limits for an unrestricted area? A restricted area?

5. You, as disposal officer, are given a 100 ml, sample of liquid from a storage tank containing Cesium-134 in solution. After evaporating the material, you find the residual solid gives a reading of 45 cpm on the scaler. At this counting rate, the scaler is 0.10% efficient. Can the solution in the storage tank be disposed of through the sanitary sewage system? Assume that the total amount of material for disposal is less than 1 Ci.

6. You as disposal officer are given a small amount of liquid solution containing ^{64}Cu dissolved in it. The reading you get on this sample after all corrections are made is 300,000 disintegrations per minute. You wish to dispose of this nuclide through the sanitary sewage system. What action must be taken?

7. A soluble nuclide was accidentally spilled and the decontamination resulted in the collection of 50 liters of water. The nuclide was determined to be $^{65}_{28}Ni$ and the reading before decontamination was 480,000 dpm. Would it be permissible to dispose of this water through the sanitary sewer?

8. A 200 mCi sample of $^{51}_{24}Cr$ is to be shipped.

a. What transport group does this isotope fall under and what would be the most economical type package?

b. How much lead must be used to allow shipment of this material as a Yellow III label item? The package used measures 0.5 meters to a side.

9. You, as Radiological Safety Officer, have been asked to check a container to ship 1 Ci of $^{185}_{76}Os$. You decide to use lead as the inner shielding container. How much lead would be required to ship this package under radioactive Yellow III label requirements without a waiver, if the package is 1 meter to a side?

10. You have 30 curies of Au-198 in liquid form that you wish to ship without a waiver. The material can be kept in a safe storage vault until ready to ship.

   a. What transport group does this fall under, and what type package is needed?

   b. If you want to use a Yellow II label, how much lead shielding is needed if the container is to be 0.5 meter on each side? (The liquid is contained in a plastic bottle which stops the beta particles with negligible production of bremsstrahlung.)

c. If you had only type A packages available to you, what actions could you take to ship it?

d. What is the transport index for original shipment (refer to part b)? Is this within the acceptable limit?

11. Is it possible to ship 198 Ci of cobalt-60 under Yellow III label in a type B package measuring 0.5 meter on a side, without a waiver? Assume that lead is used for shielding. Neglect dose rate buildup.

12. What size container would be necessary to ship the radionuclide in problem 11 under radioactive White I label without any shielding?

13. An airborne sample gave a count of 256 cpm after 4 hours. At 28 hours the count was 218 cpm. The background count was 6 cpm. The collector was 80% efficient; the counter was 5% efficient. The volume of air filtered was 10,000 cubic feet.

a. What is the airborne concentration of the long-lived radioactive component, expressed in μCi/ml?

b. If the radionuclide is unknown, does the concentration exceed the limit for an unrestricted area?

14. A 5 mCi sample of technetium-96 is to be shipped. You would like to ship the material under a Radioactive Yellow III label without adding shielding or securing a special exemption from the AEC. What is the minimum sized container that may be used?

15. For determining source strength and the effect of shielding, what energies and percentages should be considered for a sample of iridium-192?

16. Your laboratory utilizes the following radionuclides in quantities not to exceed 100 mCi in activity: Cerium-141, rubidium-86, mercury-203, and gold-198. You have uncovered an unknown radioactive source that registers a dose rate of 5.5 mrad/hr at 2 meters. What is the radionuclide? What is its activity, in mCi? (Assume the unknown source is a single radionuclide. Assume the dose rate is only due to gamma radiation.)

17. a. Can 1.5 mCi of silver-108m be shipped radioactive White I label in a type A container measuring 0.5 meter on a side without using any shielding?

b. Can the material in part (a) be shipped radioactive White I label in a 10 cm thick lead container inside a type A package measuring 0.5 meter on a side without requiring additional shielding?

18. A 100 mCi of arsenic-73 is to be shipped. You would like to ship the material radioactive Yellow II label in a type A container measuring 1 meter on a side. How much lead would be required to shield the sample to meet these requirements?

19. The dose rate at 5 meters from a source of zinc-65, which is contained within 2 cm thick aluminum, is 10 rad/hr. What is the activity of the source in Ci?

V. Solutions:

1. Radon and Thoron

$({}^{222}_{86}Rn + {}^{220}_{86}Rn)$

They are descendants of ^{226}Ra and ^{228}Th (see page 363, Pam 25).

2. $C_{LL} = \frac{C_2 - C_1\phi}{1 - \phi}$

$C_2 = 45,200$

$C_1 = 53,800$

$\phi = 0.270$ for $\Delta t = 20$

In reality we should subtract the background count from 45,200 cpm and 53,800 cpm to get C_1 and C_2. Since 26 cpm is such a small number in comparison with 53,800 and 45,200, it will not make much difference in our answer so we will neglect it for this problem.

$$C_{LL} = \frac{45,200 - (53,800)(0.270)}{1 - 0.270}$$

$$= \frac{45,200 - 14,500}{0.73}$$

$$= \frac{30,700}{0.73}$$

$$= 42,000 \text{ cpm}$$

cpm

3. $\mu Ci/ml = \frac{C_{LL}}{V \times E_f \times E_c} \times 4.505 \times 10^{-7}$

V in ml

$$V = 3\text{ hr} \times \frac{60\text{ min}}{\text{hr}} \times \frac{20\text{ ft}^3}{\text{min}} \times \frac{2.83 \times 10^4\text{ ml}}{\text{ft}^3} =$$

$$3.6 \times 10^3 \times 2.83 \times 10^4\text{ ml} = 102 \times 10^6\text{ ml}$$

$E_f \times E_c = 10\%\ \ 0.10$

$$\mu Ci/ml = \frac{2 \times 10^4 \times 4.505 \times 10^{-7}}{10^{-1} \times 1.02 \times 10^8}$$

$$= 8.83 \times 10^{-10}\ \mu Ci/ml$$

4. Yes. No.

5. Efficiency $= \frac{cpm}{dpm}$

$$dpm = \frac{45\text{ cpm}}{0.001} = 45000\text{ dpm}$$

$$45{,}000\text{ dpm} \times \frac{1\text{ min}}{60\text{ sec}} = 750\text{ dis/sec}$$

$$750\ \frac{\text{dis}}{\text{sec}} \times \frac{1\text{Ci}}{3.7 \times 10^{10}\text{ dis/sec}} \times \frac{10^6\ \mu Ci}{1\text{ Ci}} = 2.03 \times 10^{-2}\ \mu Ci$$

$$\frac{2.03 \times 10^{-2}\ \mu Ci}{100\text{ ml}} = 2.03 \times 10^{-4}\ \mu Ci/ml$$

From Title 10, Part 20, Appendix B

Table I, Column 2 - for ^{134}Cs

have $3 \times 10^{-4}\ \mu Ci/ml$

$2.03 \times 10^{-4} < 3 \times 10^{-4}$

Yes, storage tank solution can be disposed of through the sanitary sewage system.

6. Correct reading to µCi

$$\frac{300{,}000\text{ dis/min}}{60\text{ sec/min}} = 5000\text{ dis/sec}$$

$$\frac{5 \times 10^3\text{ dis/sec}}{3.7 \times 10^{10}\text{ dis/sec/Ci}} = 1.35 \times 10^{-7}\text{ Ci or } 1.35 \times 10^{-1}\ \mu Ci$$

From App B ^{64}Cu Sol	From App C ^{64}Cu
$1 \times 10^{-2}\ \mu Ci/ml$	100 µCi

From App C

$100\ \mu Ci \times 10 = 1000\ \mu Ci$

we have $1.35 \times 10^{-1}\ \mu Ci$

It can be disposed of by dumping, if it meets the requirement of dilution with the monthly water supply.

$$\frac{1.35 \times 10^{-1}\ \mu Ci}{1 \times 10^{-2}\ \mu Ci/ml} = 13.5 \text{ ml of water dumped in sewer that month}$$

to allow disposal.

7. Correct reading to µCi

$$\frac{480{,}000 \text{ dis/min}}{60 \text{ sec/min}} = 8000 \text{ dis/sec}$$

$$\frac{8 \times 10^3 \text{ dis/sec}}{3.7 \times 10^{10} \text{ dis/sec/Ci}} = 2.16 \times 10^{-7} \text{ curies or } 2.16 \times 10^{-1}\ \mu Ci$$

From App B

Table I, Column II Sol

^{65}Ni —— $4 \times 10^{-3}\ \mu Ci/ml$

From App C

100 µCi

$100\ \mu Ci \times 10 = 1000\ \mu Ci$
We have $2.16 \times 10^{-1}\ \mu Ci$ - meets the requirement.

To meet the dilution requirement

$$\frac{2.16 \times 10^{-1}\ \mu Ci}{4 \times 10^{-3}\ \mu Ci/ml} = 0.54 \times 10^{2} \text{ ml or 54 ml of water.}$$

The total water used was 50 liters. If this is the average daily sewage water, it can be dumped.

8. a. This radioactive material is a transport group IV item. The most economical type package would be type A since it falls within the limits of this type.

b. Calculate the source strength.

$S = 0.56$ nCE

$S = 0.56 \times 0.09 \times 0.3198 \times 200$

$S = 3.22$ mrhm

Since the package is 0.5 meter to a side, if the source is located in the center, it will be 0.25 meter from the nearest side. $d = 0.25$ meter.

$R = \frac{S}{d^2}$

$R = \frac{3.22 \text{ mrhm}}{(0.25)^2}$

$R = \frac{3.22}{0.0625}$

$R = 51.52$ mrad/hr at the surface

$R = \frac{S}{d^2}$

$R = \frac{S}{(1.25)^2}$

$R = \frac{3.22}{1.56}$

$R = 2.06$ mrad/hr at 1 meter from the surface

∴ No shielding is required since both requirements are met.

9. Calculate the source strength.

$S = 0.56$ nCE

$S_1 = 0.56 \times 0.14 \times 1 \times 0.875$

$S_1 = 0.0686$ rhm

$S_2 = 0.56 \times 0.80 \times 1 \times 0.646$

$S_2 = 0.289$ rhm

$S_t = 0.0686 \text{ rhm} + 0.289 \text{ rhm}$

$S_t = 0.358$ rhm

<u>Find R at surface</u>

$d = 0.5$ meter

$R_o = \frac{S}{d^2}$

$R_o = \frac{0.358}{(0.5)^2}$

$R_o = \frac{0.358}{0.25}$

$R_o = 1.436$ rad/hr at surface

$R_o = 1436$ mrad/hr

$R = 200$ mrad/hr

$$X_{\frac{1}{2}} = \frac{0.693}{\mu}$$

$$X_{\frac{1}{2}} = \frac{0.693}{0.930}$$

$$X_{\frac{1}{2}} = 0.745 \text{ cm}$$

$$2^n = \frac{1436}{200}$$

$$2^n = 7.18$$

$$n = 2.9 \ (2^n \text{ Table})$$

$$n = \frac{X}{X_{\frac{1}{2}}}$$

$$2.9 = \frac{X}{0.745 \text{ cm}}$$

$$X = 2.16 \text{ cm}$$

μ/ρ for 0.875 Mev gamma in lead $= 0.0819 \text{ cm}^2/\text{gm}$

$\mu = \mu/\rho \times \rho = 0.0819 \text{cm} \times 11.35 = 0.930 \text{ cm}^{-1}$

<u>Find R at 1 meter from surface</u>

$$d = 1.5 \text{ meters}$$

$$R_o = \frac{0.358}{2.25}$$

$$R_o = 160 \text{ mrad/hr}$$

$$R = 10 \text{ mrad/hr}$$

$$2^n = \frac{160}{10}$$

$$2^n = 16.0$$

$$n = 4.0$$

$$n = \frac{X}{X_{\frac{1}{2}}}$$

$$4.0 = \frac{X}{0.745 \text{ cm}}$$

$$X = 2.98 \text{ cm}$$

To meet all requirements, 2.98 cm of lead must be used on a side.

10. a. This is a transport group IV item. A type B package must be used since the limit for type A packages (20 Ci) is exceeded, but is below the limit for type B (200 Ci).

b. Calculate the source strength (from page 405, Pam 25).

$$S = 0.56 \text{ nCE}$$

$$S = 0.56 \times 0.99 \times 30 \times 0.4118$$

$$S = 6.84 \text{ rhm} = 6840 \text{ mrhm}$$

Surface Requirement

$d = 0.25$ meter

$R_o = \dfrac{S}{d^2}$

$R_o = \dfrac{6840}{(0.25)^2}$

$R_o = 109{,}440$ mrad/hr

Reduce to 10 mrad/hr

3 ft (1 m) Requirement

$d = 1.25$ meters

$R_o = \dfrac{S}{d^2}$

$R_o = \dfrac{6840}{(1.25)^2}$

$R_o = 4{,}360$ mrad/hr

Reduce to 0.5 mrad/hr

μ/ρ for 0.412 gamma $= 0.223\ cm^2/gm$

$$0.10 \left[\begin{array}{ll} 0.012 \left[\begin{array}{ll} 0.400 & 0.231 \\ 0.412 & \mu/\rho \end{array} \right] X & \\ \quad 0.500 & 0.161 \end{array} \right] 0.070$$

$$\frac{0.012}{0.100} \qquad \frac{X}{0.070}$$

$$X = \frac{0.070 \times 0.012}{0.100}$$

$$X = 0.0084$$

$$\mu/\rho = 0.231 - 0.008$$

$$= 0.223$$

$$\mu = \mu/\rho \times \rho = 0.223 \times 11.35 = 2.53\ cm^{-1}$$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{2.53} = 0.274\ cm$$

At Surface

$R_o = 109{,}440$ mrad/hr

$R = 10$ mrad/hr

$X_{1/2} = 0.277$

$2^n = \dfrac{109{,}440}{10} = 10{,}944$

At 1 m from Surface

$R_o = 4{,}360$ mrad/hr

$R = 0.5$ mrad/hr

$X_{1/2} = 0.277$

$2^n = \dfrac{4360}{0.5} = 8{,}720$

$n' = 13.5$ | $n = 13.1$

$X = nX_{1/2} = 13.5 \times 0.274$ | $X = nX_{1/2} = 13.1 \times 0.274$

$X = 3.70$ cm | $X = 3.59$ cm

To meet all requirements 3.70 cm of lead must be used on each side.

c. (1) Allow the isotope to decay in the storage vault until its activity is 20 Ci or less. Since the half-life is only 2.7 days, it will take less than 2 days for the desired level to be attained.

(2) The isotope can be divided and shipped in two separate type A packages. The activity in each would be 15 Ci, which is within the limit.

d. Transport index is 0.5. This is within the acceptable limit (50).

11. Data on ^{60}Co (page 389, Pam 25)

γ energy (total) - 2.5057 Mev ($99^+\%$)

β^- energy - 0.319 Mev ($99^+\%$)

$$S_\gamma = 0.56\ nCE$$
$$= 0.56 \times 0.99 \times 198\ Ci \times 2.5057\ Mev$$
$$= 275\ rhm$$
$$S_{Brem} = 1.85 \times 10^{-4}\ nCZE_\beta^2$$
$$= 1.85 \times 10^{-4}\ (0.99)(198)(82)(0.319)^2$$
$$= 0.302\ rhm$$
$$S_T = S_\gamma + S_{brem}$$
$$= 275 + 0.302 = 275.3\ rhm$$

Surface requirement ($d = 0.25$ m):

$$R_o = \frac{S}{d^2}$$
$$= \frac{275.3\ rhm}{(0.25\ m)^2}$$
$$= 4400\ rad/hr = 4.4 \times 10^6\ mrad/hr$$
$$2^n = \frac{R_o}{R}$$
$$= \frac{4.4 \times 10^6\ mrad/hr}{200\ mrad/hr}$$
$$= 2.2 \times 10^4 = 22000$$
$$n = 14.5\ (2^n\ \text{Table})$$

μ/ρ for 1.332 Mev. = 0.0581 cm^2/gm

ρ = 11.35 gm/cm^3

$\mu = \frac{\mu}{\rho}\rho = 0.0581 \frac{cm^2}{gm} \times 11.35 \frac{gm}{cm^3}$

$= 0.659\ cm^{-1}$

$X_{1/2} = 0.693/\mu$

$= 0.693/0.659\ cm^{-1}$

$= 1.05\ cm$

$X = nX_{1/2}$

$= 14.5 \times 1.05\ cm$

$= 15.225\ cm$

15.225 cm < 25 cm. Conditions in problem are possible for surface requirements.

One meter requirement (d = 1.25 m):

$R_o = \frac{S}{d^2}$

$= \frac{275.3\ rhm}{(1.25\ m)^2}$

$= 176.2\ rad/hr = 1.762 \times 10^5\ mrad/hr$

$2^n = \frac{R_o}{R}$

$= \frac{1.762 \times 10^5\ mrad/hr}{10\ mrad/hr}$

$= 17620$

$n = 14.2$ (2^n Table)

$X = nX_{1/2}$

$= 14.2 \times 1.05\ cm$

$= 14.9\ cm$

14.9 cm < 25 cm. Conditions in problem are possible for 1 meter requirement.

Yes, problem conditions are possible, but obviously not practical:

12. From problem (1):

$R_o = 0.5$ mrad/hr for White I label

$$d^2 = \frac{S}{R_o}$$

$$= \frac{2.783 \times 10^5 \text{ mrhm}}{0.5 \text{ mrad/hr}}$$

$$= 5.566 \times 10^5 \text{ m}^2$$

d = 745 meters

side of container = 2 x 745 meters = 1490 meters

Again, highly impractical.

13. a. C_1 = 256 cpm - 6 cpm = 250 cpm at 4 hours

C_2 = 218 cpm - 6 cpm = 212 cpm at 28 hours

Φ for (28 - 4) = 24 hours is 0.208

$$C_{LL} = \frac{C_2 - C_1\Phi}{1 - \Phi}$$

$$= \frac{212 - 52}{1 - 0.208}$$

$$= \frac{160}{0.792}$$

$$= 202 \text{ cpm}$$

$$\text{ml} = (\text{ft}^3) \times (2.832 \times 10^4)$$

$$= 10{,}000 \text{ ft}^3 \times 2.832 \times 10^4$$

$$= 2.832 \times 10^8 \text{ ml}$$

$$\text{dis/min-ml} = \frac{C_{LL}}{V(\text{ml}) \times E_{ff} \times E_{fc}}$$

$$= \frac{202 \text{ cpm}}{2.832 \times 10^8 \text{ ml} \times 0.80 \times 0.05}$$

$$= 1.783 \times 10^{-5}$$

$$\mu Ci/ml = (dis/min\text{-}ml) \times 4.505 \times 10^{-7})$$
$$= 1.783 \times 10^{-5} \times 4.505 \times 10^{-7}$$
$$= \underline{8.03 \times 10^{-12}}$$

b. Title 10, Part 20, Appendix B, Note 2, establishes 2.0×10^{-14} µCi/ml as the limiting value for an unknown radionuclide for Table II, Column 1 (lower limit for unrestricted area).

8.03×10^{-12} µCi/ml $> 2.0 \times 10^{-14}$ µCi/ml

The concentration <u>does</u> exceed the limit for an unrestricted area.

14. Data on ^{96}Tc (page 274, Pam 25)

γ energies - Total

0.32 (5%)
0.778 (100%)
0.81 (84%)
0.851 (100%)
1.12 (16%)

$$S = 0.56\, C \sum nE$$
$$= (0.56)\,(5mCi)\left[(0.05)(0.32) + (1)(0.778) + (0.84)(0.81) + (1)(0.851) + (0.16)(1.12)\right]$$
$$= (0.56)(5mCi)(0.016+0.778+0.6804+0.851+0.1792) = (0.56)(5mCi)(2.505)$$
$$= 7.01$$

Surface requirement:

$$d^2 = \frac{S}{R_o} = \frac{7.01 \text{ mrhm}}{200 \text{ mrad/hr}}$$
$$= 0.03505 \text{ m}^2$$
$$d = 0.187 \text{ meter}$$

container size = 2 x 0.187 = 0.374 meter

One meter requirement:

$$d^2 = \frac{S}{R_o} = \frac{7.01 \text{ mrhm}}{10 \text{ mrad/hr}}$$
$$= 0.701 \text{ m}^2$$
$$d = 0.838 \text{ meter}$$

Container size = 2 x 0.838 = 1.676 meter.

Use 1 meter requirement. Minimum size of container is <u>1.676m per side.</u>

15. Refer to page 403, Pam 25, for energies and percentages for source strength.

β^- energy and percentages

0.672 Mev (49%)
0.536 Mev (42%)
0.24 Mev (4.5%)

Refer to page 403, Pam 25, for maximum beta energy for shielding - 0.672 Mev.

γ energy and percentages

1.20099 (4.5%)
0.92087 (42%)
0.78454 (49%)
0.6904 (3.9%)

Refer to page 342, Pam 25, for maximum gamma energy for shielding - 0.612 Mev.

Neglect β^-, β^+, and γ energies at less than 3% frequency.

16. Data on ^{141}Ce (page 401, Pam 25)

γ energy - 0.1453 Mev (70%)

Data on ^{86}Rb (page 391, Pam 25)

γ energy - 1.078 Mev (8.8%)

Data on ^{203}Hg (page 405, Pam 25)

γ energy - 0.2791 Mev (100%)

Data on ^{198}Aug (page 405, Pam 25)

γ energy - 0.4118 Mev (99%)

Neglect all particulate energies.

$$R_o = \frac{S}{d^2}$$

$$S = R_o d^2 = 5.5 \text{ mrad/hr} \times (2 \text{ m})^2$$

$$= 22 \text{ mrhm}$$

Calculate the activity of each of the radionuclides equivalent to a source strength of 22 mrhm.

$$S = 0.56 \text{ nCE}$$

$$C = \frac{S}{0.56 \text{ nE}}$$

for ^{141}Ce:

$$C = \frac{22 \text{ mrhm}}{0.56 \times 0.7 \times 0.14543 \text{ Mev}}$$

$= 386$ mCi - Impossible (>100 mCi)

for ^{86}Rb:

$$C = \frac{22 \text{ mrhm}}{0.56 \times 0.088 \times 1.078 \text{ Mev}}$$

$= 414$ mCi - Impossible

for ^{203}Hg:

$$C = \frac{22 \text{ mrhm}}{0.56 \times 1.0 \times 0.2791 \text{ Mev}}$$

$= 141$ mCi - Impossible

for ^{198}Au:

$$C = \frac{22 \text{ mrhm}}{0.56 \times 0.99 \times 0.4118 \text{ Mev}}$$

$= 96.4$ mCi

Thus, ^{198}Au must be the unknown radionuclide.

17. a. Data on ^{108m}Ag (page 282, Pam 25)

γ energies - 0.08 (5%)
0.434 (89%)
0.614 (90%)
0.722 (90%)

$S = 0.56 \; C \Sigma nE$

$= (0.56)(1.5 \text{ mCi})[(0.05)(0.08)+(0.89)(0.434)+(0.9)(0.614)+(0.9)(0.722)]$

$= (0.56)(1.5\text{mCi})(0.004+0.386+0.553+0.650)$

$= 1.339$ mrhm

$$R_o = \frac{S}{d^2}$$

$$= \frac{1.339 \text{ mrhm}}{(0.25 \text{ m})^2}$$

$$= 21.4 \text{ mrad/hr}$$

Radioactive White I label requires that the surface dose rate be less than 0.5 mrad/hr.

Thus, this source cannot be shipped under a White I label.

b. $R_o = 21.4$ mrad/hr

$R = ?$

$X = 1$ cm

Use $E_{\gamma max} = 0.722$ Mev

$\mu/\rho = 0.1027 \text{ cm}^2/\text{gm}$

$$\mu = \mu/\rho \times \rho = 0.1027 \text{ cm}^2/\text{gm} \times 11.35 \text{ gm/cm}^3$$

$$= 1.167 \text{ cm}^{-1}$$

$$X_{\frac{1}{2}} = \frac{0.693}{\mu} = \frac{0.693}{1.167 \text{ cm}^{-1}} = 0.594 \text{ cm}$$

$$n = \frac{X}{X_{\frac{1}{2}}} = \frac{3 \text{ cm}}{0.594 \text{ cm}} = 5.05$$

$2^n = 32$ (2^n Table)

$$R = \frac{R_o}{2^n} = \frac{21.4 \text{ mrad/hr}}{32}$$

$$= 0.669 \text{ mrad/hr}$$

Thus, the source cannot be shipped radioactive White I label when we consider 3 cm of lead shielding since the dose rate is greater than 0.5 mrad/hr.

18. Data on ^{73}As (page 256, Pam 25)

γ energy - 0.054 Mev (9%)

No particulate energy.

$$S = 0.56 \text{ nCE}$$

$$= 0.56 \times 0.09 \times 100 \text{ mCi} \times 0.054 \text{ Mev}$$

$$= 0.272 \text{ mrhm}$$

Surface requirement:

$$R_o = \frac{S}{d^2} = \frac{0.272 \text{ mrhm}}{(0.5 \text{ m})^2}$$

$$= 1.09 \text{ mrad/hr} < 10 \text{ mrad/hr} \quad \text{OK}$$

One meter requirement:

$$R_o = \frac{S}{d^2} = \frac{0.272 \text{ mrhm}}{(1.5 \text{ m})^2}$$

$$= 0.0121 \text{ mrad/hr}$$

$0.0121 \text{ mrad/hr} < 0.5 \text{ mrad/hr}$ OK

Thus, no shielding is necessary to meet Yellow II label requirements.

19. Data on ^{65}Zn (page 390, Pam 25)

γ energies - 1.115 Mev (49%)

$$R = 10 \text{ rad/hr}$$

$$X = 2 \text{ cm}$$

$$\frac{\mu}{\rho} = 0.0587 \text{ cm}^2/\text{gm}$$

$$\rho = 2.699 \text{ gm/cm}^3$$

$$\mu = \frac{\mu}{\rho}\rho = 0.0587 \text{ cm}^2/\text{gm} \times 2.699 \text{ gm/cm}^3$$

$$= 0.158 \text{ cm}^{-1}$$

$$X_{1/2} = \frac{0.693}{\mu} = \frac{0.693}{0.158 \text{ cm}^{-1}}$$

$$= 4.39 \text{ cm}$$

$$n = \frac{X}{X_{1/2}} = \frac{2\ \text{cm}}{4.39\ \text{cm}}$$

$$= 0.456$$

2^n 1.415 (2^n Table)

$$R_o = R \times 2^n = 10\ \text{rad/hr} \times 1.415$$

$$= 14.15\ \text{rad/hr}$$

$$S = R_o d^2 = 14.15\ \text{rad/hr} \times (5\ \text{m})^2$$

$$= 354\ \text{rhm}$$

$$S = 0.56\ nCE$$

$$S = 0.56 \times 0.49 \times C \times 1.115\ \text{Mev} = 0.306\ C\ \text{rhm}$$

Since $S = 354$ rhm

$$C = \frac{354\ \text{rhm}}{0.306}$$

$$= \underline{\underline{1157\ \text{Ci}}}$$

REFERENCES FOR RADIOLOGICAL SAFETY

DZ040, References for Radiological Safety

I. References.

A. Special Texts and Pamphlets.

1. ST 3-155, The Theory and Operation of Radiac Instruments.

2. Pam 25, Radiological Handbook.

3. Radiological Safety Handbook.

B. Department of the Army Publications.

1. General:

FM 3-8, Chemical Corps Reference Handbook
FM 3-12, Operational Aspects of Radiological Defense.
FM 21-40, Chemical, Biological, Radiological and Nuclear Defense.
FM 21-21, Soldier's Handbook for Defense Against Chemical and Biological Operations and Nuclear Warfare.
TM 38-750, The Army Maintenance Management System (TAMMS).
DA Pam 39-3, The Effects of Nuclear Weapons.

2. Accident Control and Emergency Procedures.

AR 50-2, Nuclear Weapon Accident and Incident Control (NAIC)
AR 40-13, Radiological Emergency Medical Teams (REMT).
FM 3-15, Nuclear Accident Contamination Control.
TB 385-2, Nuclear Weapons Firefighting Procedures.
TM 3-220, CBR Decontamination.
TM 5-225, Radiological and Disaster Recovery at Fixed Military Installations.
TM 5-315, Firefighting and Rescue Operations.
DA Pam 350-9, Training in First Aid and Emergency Medical Treatment.

3. Radiac Dose Rate Instruments.

a. General.

TB Sig 225, Identification and Handling of Radioactive Signal Items.
TB Sig 346, Maintenance of Radiac Equipment.
TB 11-6665-229-15/1, Calibration and Maintenance Calibration Requirements for Radiac Equipment.

b. Radiac Set AN/PDR-27(J).

TM 11-5543, Radiac Sets AN/PDR-27(A), AN/PDR-27(C), AN/PDR-27(E).
TM 11-6665-201-12P, Radiac Sets AN/PDR-27(A), AN/PDR-27(E), AN/PDR-27(G), AN/PDR-27(J), AN/PDR-27(K).

TM 11-6665-209-15, Radiac Sets AN/PDR-27(J), AN/PDR-27(L), AN/PDR-27(Q).
TM 11-6665-223-15, Radiac Set AN/PDR-27(G).
TM 11-6665-224-15, Radiac Set AN/PDR-27(P).
TM 11-6665-230-15, Radiac Set AN/PDR-27(R).

c. Radiac Set AN/PDR-54.

TM 11-6665-208-15, Radiac Set AN/PDR-54.

d. Radiac Set AN/PDR-60 (IM-170).

TM 11-6665-216-15, Radiac Set AN/PDR-60 (PAC-1SAG).
TM 11-6665-221-15, Radiac Set AN/PDR-60 (PAC-1SAGA).

e. Radiacmeter, IM-174( )/PD.

TM 11-6665-213-12, Radiacmeter IM-174/PD.
TM 11-6665-232-12, Radiacmeter IM-174(A)/PD.

Radioactive Test Samples, Calibrators, and the Army Calibration System.

a. General.

AR 700-52, Licensing and Control of Sources of Ionizing Radiation.
AR 725-1, chapter 3, Control of Radioactive Calibration and Test Items of Supply.
AR 750-25, Army Metrology and Calibration System.
FM 39-27, Army Calibration Company.
TB Med 249, Protection Against Radiation from Sealed Gamma Sources (NBS Handbook 73).

b. Radiac Calibrator, AN/UDM-1A.

TM 11-6665-217-15, Radiac Calibrator Set, AN/UDM-1A.

c. Radiac Calibrator AN/UDM-6.

TB 3-6665-203-12, Calibrator, Radiac, AN/UDM-6.

d. Radiac Calibrator Set, TS-784( )/PD.

TB 11-6665-204-12, Safe Handling, Storage, and Transportation of Calibrators, Radiac, TS-784( )/PD.
TM 11-6665-204-12, Calibrators, Radiac, TS-784( )/PD.
TM 11-6665-204-50, Calibrators, Radiac, TS-784( )/PD.
TB 9-6665-280-50, Calibration Procedures for Radiac Calibrator TS-784( )/PD.

e. Source Set M3 and M3A1.

TM 3-6665-214-15, Radioactive Source Sets M3 and M3A1.
SB 3-30-209, Radioactive Source Set M3, Serviceability Standard.

f. Test Sample, M6.

TB Cml 52, Radioactive Test Sample; Strontium-90, Yttrium-90, M6.

g. Test Sample, M7.

TM 3-6665-271-10, Radioactive Test Sample, Uranium Oxide, Alpha, M7.

h. Test Sample, M8.

AMTC 1639, Radioactive Test Sample, U_3O_8, M8.
TM 3-6665-300-10, Radioactive Test Sample, Uranium Oxide, Alpha, M8.

i. Test Sample, M9.

TB 3-6665-259-10, Radioactive Test Sample, M9.
TB 9-6665-280-50, Calibration Procedures for Radiac Calibrator TS-784( )/PD.

j. Test Sample, MX1083( )/PDR-27( ).

TB 3-6665-200-12, Radioactive Test Sample MX1083/PDR-27.
TB 3-6665-201-12, Radioactive Test Sample MX1083B/PDR-27.
TB 3-6665-204-12, Radioactive Test Sample MX1083D/PDR-27.
SB 3-30-300, Radioactive Test Samples, Serviceability Standard.

k. Test Sample, MX7338/PDR-27R.

TM 3-6665-264-10, Radioactive Test Sample MX7338/PDR-27R.

5. Radiation Dosimetry.

AR 40-2?, Personnel Radiation Exposures.
AR 40-14, Control and Recording Procedures Occupational Exposure to Ionizing Radiation.
TB Sig 226-8, Charger, Radiac Detector, PP-1578A/PD.
TB 11-6665-215-12/1, Charger, Radiac Detector, PP-1578A/PD.
TM 11-6665-214-10, Radiacmeters IM-93( )/UD, IM-147/PD, and IM-9E/PD.
SB 11-206, Film Badge Supply and Service for Technical Radiation Exposure Control.

6. Waste Disposal.

AR 755-15, Disposal of Unwanted Radioactive Material.
TM 3-260, Operation of Radioactive Material Disposal Facilities.
TM 3-261, Handling and Disposal of Unwanted Radioactive Material.
SB 5-108, Disposition of Excess Radioactive Engineer Personal Property.

7. Transportation of Radioactive Materials.

AR 55-55, Transportation of Radioactive Fissile Materials Other than Weapons.
TB TC 7, Safe Transport of Radioactive Materials:
TM 55-602, Movement of Special Freight.

C. NCRP Reports.

1. No. 8, Control and Removal of Radioactive Contamination in Laboratories (1951).

2. No. 9, Recommendations for Waste Disposal of Phosphorus-32 and Iodine-131 for Medical Users (1951).

3. No. 12, Recommendations for the Disposal of Carbon-14 Wastes (1953).

4. No. 14, Protection Against Betatron-Synchrotron Radiations up to 100 Million Electron Volts (1954).

5. No. 16, Radioactive Waste Disposal in the Ocean (1954).

6. No. 17, Permissible Dose from External Sources of Ionizing Radiation (1954) with Addendum (1958).

7. No. 20, Protection Against Neutron Radiation up to 30 Million Electron Volts.

8. No. 21, Safe Handling of Bodies Containing Radioactive Isotopes (1958).

9. No. 22, Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure (1959) with addendum (1963).

10. No. 23, Measurement of Neutron Flux and Spectra for Physical and Biological Applications (1960).

11. No. 24, Protection Against Radiations from Sealed Gamma Sources (1960).

12. No. 25, Measurement of Absorbed Dose of Neutrons and Mixtures of Neutrons and Gamma Rays (1967).

13. No. 26, Medical X-Ray Protection up to Three Million Volts (1961).

14. No. 27, Stopping Powers for Use with Cavity Chambers (1961).

15. No. 28, A Manual of Radioactivity Procedures (1961).

16. No. 29, Exposure to Radiation in an Emergency.

17. No. 30, Safe Handling of Radioactive Materials (1964).

18. No. 31, Shielding for High-Energy Electron Accelerator Installations (1964).

19. No. 32, Radiation Protection in Educational Institutions (1966).

20. No. 33, Medical X-Ray and Gamma-Ray Protection for Energies up to 10 Mev - Equipment Design and Use (1968).

21. No. 34, Medical X-Ray and Gamma-Ray Protection for Energies up to 10 Mev - Structural Shielding Design and Evaluation (1970).

22. No. 35, Dental X-Ray Protection (1970).

Note: NCRP reports have replaced National Bureau of Standards Handbooks. They are available from:

NCRP Publications
Post Office Box 4867
Washington, D. C. 20008

D. Code of the Federal Register, Title 10.

1. Part 20, Standards for Protection.

2. Part 30, Licensing of Byproduct Material.

3. Part 31, Radiation Safety Requirements for Radiographic Operations.

4. Part 40, Control of Source Material.

5. Part 70, Control of Special Nuclear Material.

E. Tarrif No. 23, Agent T.C. George, Publisher, Department of Transportation. Transportation of Explosives and Other Dangerous Articles by Land and Water in Rail Freight Service and by Motor Vehicles and Water, including Specifications for Shipping Containers.

F. Jerome E. Summer, Jr., "General Handbook for Radiation Monitoring," LA-1835 (3d Ed.), Los Alamos Scientific Laboratory, Los Alamos, New Mexico, 1958.

G. Handbooks.

1. Table of Isotopes, 6th Ed., C. M. Lederer, J. M. Hollander, and I. Perlman, 1967, John Wiley & Sons, Inc., New York.

2. Radiological Health Handbook, Jan 1970, US Dept of HEW, PHS; Rockville, Md 20852.

H. Textbooks.

1. T. Moeller, "Inorganic Chemistry," John Wiley & Sons, 1952.

2. R. D. Evans, "The Atomic Nucleus," McGraw-Hill Book Co., 1955.

3. J. B. Birks, "Scintillation Counters," Pergamon Press, New York, 1960.

4. M. Haissinsky, "The Chemical and Biological Action of Radiations," Academic Press, London, 1961.

5. A. A. Keil, "Radiation Control for Fire and other Emergency Forces," National Fire Protection Association, 1960.

6. R. T. Overman and H. M. Clar, "Radioisotope Techniques," McGraw-Hill Book Co., 1960.

7. G. D. Chase and J. L. Rabinowitz,"Principles of Radioisotope Methodology," Burgess Publishing Co., 1962.

8. W. J. Moore, "Physical Chemistry," 2d Ed., Prentiss Hall, Inc., 1955.

9. E. deBarry Barnell and C. L. Wilson, "Inorganic Chemistry, 2d Ed., Longman's, Green & Co., 1957.

10. H. Semat, "Introduction to Atomic and Nuclear Physics," 4th Ed., Rinehart & Co., 1954.

11. G. Friedlander and J. W. Kennedy, "Nuclear and Radiochemistry," John Wiley & Sons, 1955.

12. H. Blatz, Editor, "Radiation Hygiene Handbook," McGraw-Hill Book Co., 1958. 2d Ed., 1964.

13. W. J. Price, "Nuclear Radiation Detection," McGraw-Hill Book Co., 1958. 2d Ed., 1964.

I. Periodicals.

1. G. N. Walton, "Nuclear Fission," Quarterly Reviews 15, 1, 1961.

2. W. L. Bush and R. K. Swank, "Efficient Plastic Scintillators," Nucleonics 11, 11, 1953.

3. R. K. Swank, Nucleonics 12, 14, 1954.

J. Other Publications.

1. Oak Ridge Radioisotope Conference, "Research Application to Physical Science and Engineering," 1963.

2. H. Goldstein and J. E. Wilkins, Jr., "Calculations of the Penetration of Gamma Rays," NYO3075, USAEC.

II. Lesson Plan Outline:

A. As new uses for ionizing radiation are being incorporated into the military, the quantity of radioisotopes and radiation producing devices at individual US Army installations is increasing immeasurably. There has been a corresponding increase in the need for qualified Radiological Protection Officers (RPO). Interviews with Chemical Officers at various installations indicate that usually a Chemical Corps Officer is assigned the additional duty of RPO. The purpose of this article is fourfold:

1. To define the duties of the RPO.

2. To list pertinent references necessary for the performances of these duties.

3. To give additional information not covered by regulations.

4. To list the training available in radiological safety.

B. A Radiological Protection Officer is defined by Army regulation as: "an individual designated by the commander or activity to provide consultation and advice on the degree of hazards associated with ionizing radiation and the effectiveness of measures to control these hazards." His specific duties include advising the commander and his staff on the handling, storage, and shipping of radioactive material and radioactive waste. The RPO conducts environmental surveys to include instrument surveys, radiological smears or wipes, and air sampling, as required. The RPO is required to conduct a semiannual physical inventory of all radioactive materials under his control and maintain appropriate records. He will have to maintain some type of dosimetry and appropriate records for any radiation workers he may have on the installation. And finally, the RPO may be required to have a Nuclear Regulatory Commission (NRC) license or DA authorization for certain types and quantities of radioactive materials.

C. It becomes obvious that the title Radiological Protection Officer may encompass anything from an assigned additional duty to a full time job depending on the type and amount of radioactive materials or radiation producing devices on the installation. In order to fulfill his assigned duties, the RPO must be familiar with the pertinent basic regulations. Congress has established, by law, the general radiological safety requirements. These requirements are contained in Title 10, Code of Federal Regulations (10 CFR) which is available from the Government Printing Office. Part 20, 10 CFR, Standards for Protection Against Radiation, is the basic reference for radiological safety. Parts 30, 31, 33, 34, and 40 apply to specific licensing requirements for NRC licenses. The Army regulations all use 10 CFR as a basic reference.

D. While the previously listed reference materials may appear exhaustive, not all the information needed can be readily extracted. For example, no individual license or DA authorization is required for the M3 Source Set or the TS-784 Radiac Calibrator. These items are licensed to APG-EA (M3) and to Lexington Army Depot (TS-784). Additional information is contained in AR 725-1, chapter 3, dated 22 September 1970. Film badge service is available from Lexington Army Depot and Sacramento Army Depot. Pertinent information is contained in SB 11-206. The US Army Environmental Hygiene Agency provides radiological hygiene surveys and investigations in accordance with AR 725-1, chapter 3. These surveys are by request, but must be made at least once every 3 years. Technical advice on safe handling and storage of radioactive materials is available from the Surgeon General in accordance with AR 700-52. It should be apparent that the Radiological Protection Officer has a wide variety of duties and considerable responsibility. The necessary training to satisfactorily accomplish his job is available by both resident instruction (Radiological Safety Course, 3 weeks) and correspondence courses (SC 345 and 346) from the US Army Ordnance Center and School. Courses are also taught by the Department of Health, Education and Welfare. Public Health Service catalogs can be obtained from:

Director, Training and Manpower Development Program
National Center for Radiological Health
1901 Chapman Avenue
Rockville, Maryland 20852

III. Handouts: None

IV. Problems: None

V. Solutions: None

UNITED STATES NUCLEAR REGULATORY COMMISSION

RULES and REGULATIONS

TITLE 10, CHAPTER 1, CODE OF FEDERAL REGULATIONS—ENERGY

PART 19 NOTICES, INSTRUCTIONS, AND REPORTS TO WORKERS; INSPECTIONS

AUTHORITY: Secs 53, 63, 81, 103, 104, 161, Pub L 83–703, 68 Stat 930, 933, 935, 936, 937, 948, as amended (42 U.S.C 2073, 2093, 2111, 2133, 2134, 2201). Sec. 401, Pub. L 93–438, 88 stat. 1254 (42 U.S.C. 5891)

§ 19.1 Purpose.

The regulations in this part establish requirements for notices, instructions, and reports by licensees to individuals participating in licensed activities, and options available to such individuals in connection with Commission inspections of licensees to ascertain compliance with the provisions of the Atomic Energy Act of 1954, as amended, Title II of the Energy Reorganization Act of 1974, and regulations, orders, and licenses thereunder regarding radiological working conditions.

40 FR 8774

§ 19.2 Scope.

The regulations in this part apply to all persons who receive, possess, use, or transfer material licensed by the Nuclear Regulatory Commission pursuant to the regulations in Parts 30 through 35, 40, or 70 of this chapter, including persons licensed to operate a production or utilization facility pursuant to Part 50 of this chapter.

§ 19.3 Definitions.

As used in this part:

(a) "Act" means the Atomic Energy Act of 1954, (68 Stat. 919) including any amendments thereto;

(b) "Commission" means the United States Nuclear Regulatory Commission;

(c) "Worker" means an individual engaged in activities licensed by the Commission and controlled by a licensee, but does not include the licensee.

(d) "License" means a license issued under the regulations in Parts 30 through 35, 40, or 70 of this chapter, including licenses to operate a production or utilization facility pursuant to Part 50 of this chapter. "Licensee" means the holder of such a license.

(e) "Restricted area" means any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area.

38 FR 22217

§ 19.4 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

§ 19.5 Communications.

Except where otherwise specified in this part, all communications and reports concerning the regulations in this part should be addressed to the Director, Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Communications, reports, and applications may be delivered in person at the Commission's offices at 1717 H Street, NW., Washington, D.C.; or at 7920 Norfolk Avenue, Bethesda, Maryland.

40 FR 8774

§ 19.11 Posting of notices to workers.

(a) Each licensee shall post current copies of the following documents: (1) The regulations in this part and in Part 20 of this chapter; (2) the license, license conditions, or documents incorporated into a license by reference, and amendments thereto; (3) the operating procedures applicable to licensed activities; (4) any notice of violation involving radiological working conditions, proposed imposition of civil penalty, or order issued pursuant to Subpart B of Part 2 of this chapter, and any response from the licensee.

(b) If posting of a document specified in paragraph (a) (1), (2) or (3) of this section is not practicable, the licensee may post a notice which describes the document and states where it may be examined.

38 FR 22217

(c) Form NRC-3, "Notice to Employees", shall be posted by each licensee wherever individuals work in or frequent any portion of a restricted area.

NOTE: Copies of Form NRC-3 may be obtained by writing to the Director of the appropriate U.S. Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix "D", Part 20 of this chapter, or the Director, Office of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D C. 20555.

40 FR 8774

(d) Documents, notices, or forms posted pursuant to this section shall appear in a sufficient number of places to permit individuals engaged in licensed activities to observe them on the way to or from any particular licensed activity location to which the document applies, shall be conspicuous, and shall be replaced if defaced or altered.

(e) Commission documents posted pursuant to paragraph (a)(4) of this section shall be posted within 2 working days after receipt of the documents from the Commission; the licensee's response, if any, shall be posted within 2 working days after dispatch by the licensee. Such documents shall remain posted for a minimum of 5 working days or until action correcting the violation has been completed, whichever is later.

38 FR 22217

§ 19.12 Instructions to workers.

All individuals working in or frequenting any portion of a restricted area shall be kept informed of the storage, transfer, or use of radioactive materials or of radiation in such portions of the restricted area; shall be instructed in the health protection problems associated with exposure to such radioactive materials or radiation, in precautions or procedures to minimize exposure, and in the purposes and functions of protective devices employed; shall be instructed in, and instructed to observe, to the extent within the worker's control, the applicable provisions of Commission regulations

and licenses for the protection of personnel from exposures to radiation or radioactive materials occurring in such areas, shall be instructed of their responsibility to report promptly to the licensee any condition which may lead to or cause a violation of Commission regulations and licenses or unnecessary exposure to radiation or to radioactive material; shall be instructed in the appropriate response to warnings made in the event of any unusual occurrence or malfunction that may involve exposure to radiation or radioactive material; and shall be advised as to the radiation exposure reports which workers may request pursuant to § 19.13. The extent of these instructions shall be commensurate with potential radiological health protection problems in the restricted area.

§ 19.13 Notifications and reports to individuals.

(a) Radiation exposure data for an individual, and the results of any measurements, analyses, and calculations of radioactive material deposited or retained in the body of an individual, shall be reported to the individual as specified in this section. The information reported shall include data and results obtained pursuant to Commission regulations, orders or license conditions, as shown in records maintained by the licensee pursuant to Commission regulations. Each notification and report shall be in writing; include appropriate identifying data such as the name of the licensee, the name of the individual, the individual's social security number; include the individual's exposure information; and contain the following statement:

38 FR 22217

This report is furnished to you under the provisions of the Nuclear Regulatory Commission regulation 10 CFR Part 19. You should preserve this report for further reference.

(b) At the request of any worker, each licensee shall advise such worker annually of the worker's exposure to radiation or radioactive material as shown in records maintained by the licensee pursuant to § 20.401(a) and (c).

(c) At the request of a worker formerly engaged in licensed activities controlled by the licensee, each licensee shall furnish to the worker a report of the worker's exposure to radiation or radioactive material. Such report shall be furnished within 30 days from the time the request is made, or within 30 days after the exposure of the individual has been determined by the licensee, whichever is later; shall cover, within the period of time specified in the request, each calendar quarter in which the worker's activities involved exposure to radiation from radioactive materials licensed by the Commission; and shall include the dates and locations of licensed activities in which the worker participated during this period.

(d) When a licensee is required pursuant to § 20.405 or § 20.408 of this chapter to report to the Commission any exposure of an individual to radiation or radioactive material the licensee shall also provide the individual a report on his exposure data included therein. Such report shall be transmitted at a time not later than the transmittal to the Commission.

§ 19.14 Presence of representatives of licensees and workers during inspections.

(a) Each licensee shall afford to the Commission at all reasonable times opportunity to inspect materials, activities, facilities, premises, and records pursuant to the regulations in this chapter.

(b) During an inspection, Commission inspectors may consult privately with workers as specified in § 19.15. The licensee or licensee's representative may accompany Commission inspectors during other phases of an inspection.

(c) If, at the time of inspection, an individual has been authorized by the workers to represent them during Commission inspections, the licensee shall notify the inspectors of such authorization and shall give the workers' representative an opportunity to accompany the inspectors during the inspection of physical working conditions.

(d) Each workers' representative shall be routinely engaged in licensed activities under control of the licensee and shall have received instructions as specified in § 19.12.

(e) Different representatives of licensees and workers may accompany the inspectors during different phases of an inspection if there is no resulting interference with the conduct of the inspection. However, only one workers' representative at a time may accompany the inspectors.

38 FR 22217

(f) With the approval of the licensee and the workers' representative an individual who is not routinely engaged in licensed activities under control of the license, for example, a consultant to the licensee or to the workers' representative, shall be afforded the opportunity to accompany Commission inspectors during the inspection of physical working conditions.

(g) Notwithstanding the other provisions of this section, Commission inspectors are authorized to refuse to permit accompaniment by any individual who deliberately interferes with a fair and orderly inspection. With regard to areas containing information classified by an agency of the U.S. Government in the interest of national security, an individual who accompanies an inspector may have access to such information only if authorized to do so. With regard to any area containing proprietary information, the workers' representative for that area shall be an individual previously authorized by the licensee to enter that area.

§ 19.15 Consultation with workers during inspections.

(a) Commission inspectors may consult privately with workers concerning matters of occupational radiation protection and other matters related to applicable provisions of Commission regulations and licenses to the extent the inspectors deem necessary for the conduct of an effective and thorough inspection.

(b) During the course of an inspection any worker may bring privately to the attention of the inspectors, either orally or in writing, any past or present condition which he has reason to believe may have contributed to or caused any violation of the act, the regulations in this chapter, or license condition, or any unnecessary exposure of an individual to radiation from licensed radioactive material under the licensee's control. Any such notice in writing shall comply with the requirements of § 19.16(a).

(c) The provisions of paragraph (b) of this section shall not be interpreted as authorization to disregard instructions pursuant to § 19.12.

§ 19.16 Requests by workers for inspections.

(a) Any worker or representative of workers who believes that a violation of the Act, the regulations in this chapter, or license conditions exists or has occurred in license activities with regard to radiological working conditions in which the worker is engaged, may request an inspection by giving notice of the alleged violation to the Director of Inspection and Enforcement, to the Director of the appropriate Commission Regional Office, or to Commission inspectors. Any such notice shall be in writing, shall set forth the specific grounds for the notice, and shall be signed by the worker or representative of workers. A copy shall be provided the licensee by the Director of Inspection and Enforcement, Regional Office Director, or the inspector no later than at the time of inspection except that, upon the request of the worker giving such notice, his name and the name of individuals referred to therein shall not appear in such copy or on any record published, released, or made available by the Commission, except for good cause shown.

38 FR 22217

(b) If, upon receipt of such notice, the Director of Inspection and Enforcement or Regional Office Director determines that the complaint meets the requirements set forth in paragraph (a) of this section, and that there are reasonable grounds to believe that the alleged violation exists or has occurred, he shall cause an inspection to be made as soon as practicable, to determine if such alleged violation exists or has occurred. Inspections pursuant to this section need not be limited to matters referred to in the complaint.

(c) No licensee shall discharge or in any manner discriminate against any worker because such worker has filed any complaint or instituted or caused to be instituted any proceeding under the regulations in this chapter or has testified or is about to testify in any such proceeding or because of the exercise by such worker on behalf of himself or others of any option afforded by this part.

§ 19.17 Inspections not warranted; informal review.

(a) If the Director of Inspection and Enforcement or of the appropriate Regional Office determines, with respect to a complaint under § 19.16, that an inspection is not warranted because there are no reasonable grounds to believe that a violation exists or has occurred, he shall notify the complainant in writing of such determination. The complainant may obtain review of such determination by submitting a written statement of posi-

tion with the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, who will provide the licensee with a copy of such statement by certified mail, excluding, at the request of the complainant, the name of the complainant. The licensee may submit an opposing written statement of position with the Executive Director for Operations who will provide the complainant with a copy of such statement by certified mail. Upon the request of the complainant, the Executive Director for Operations or his designee may hold an informal conference in which the complainant and the licensee may orally present their views. An informal conference may also be held at the request of the licensee, but disclosure of the identity of the complainant will be made only following receipt of written authorization from the complainant. After considering all written and oral views presented, the Executive Director for Operations shall affirm, modify, or reverse the determination of the Director of Inspection and Enforcement or of the appropriate Regional Office and furnish the complainant and the licensee a written notification of his decision and the reason therefor.

38 FR 22217

(b) If the Director of Inspection and Enforcement or of the appropriate Regional Office determines that an inspection is not warranted because the requirements of § 19.16(a) have not been met, he shall notify the complainant in writing of such determination. Such determination shall be without prejudice to the filing of a new complaint meeting the requirements of § 19.16(a).

§ 19.30 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Act or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder.

40 FR 8774

A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act or any rule, regulation, or order issued thereunder, or any term, condition or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law.

38 FR 22217

§ 19.31 Application for exemptions.

The Commission may, upon application by any licensee or upon its own initiative, grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not result in undue hazard to life or property.

§ 19.32 Discrimination prohibited.

No person shall on the ground of sex be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity licensed by the Nuclear Regulatory Commission. This provision will be enforced through agency provisions and rules similar to those already established, with respect to racial and other discrimination, under title VI of the Civil Rights Act of 1964. This remedy is not exclusive, however, and will not prejudice or cut off any other legal remedies available to a discriminatee.

40 FR 8774

UNITED STATES NUCLEAR REGULATORY COMMISSION

RULES and REGULATIONS

TITLE 10. CHAPTER 1. CODE OF FEDERAL REGULATIONS—ENERGY

PART 20 STANDARDS FOR PROTECTION AGAINST RADIATION

AUTHORITY: The provisions of this Part 20 issued under secs. 53, 63, 65, 81, 103, 104, 161, 68 Stat. 930, 933, 935, 936, 937, 948, as amended; 42 U.S.C. 2073, 2093, 2095, 2111, 2133, 2134, 2201. For the purposes of sec. 223, 68 Stat. 958, as amended; 42 U.S.C. 2273, §§20.401-20.409, issued under sec. 161o., 68 Stat. 950, as amended, 42 U.S.C. 2201 (o). Secs. 202, 206, Pub. L. 93-438, 88 Stat. 1244, 1246 (42 U.S.C. 5842, 5846).

§ 20.1 Purpose.

40 FR 8774

(a) The regulations in this part establish standards for protection against radiation hazards arising out of activities under licenses issued by the Nuclear Regulatory Commission and are issued pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974.

25 FR 10914

(b) The use of radioactive material or other sources of radiation not licensed by the Commission is not subject to the regulations in this part. However, it is the purpose of the regulations in this part to control the possession, use, and transfer of licensed material by any licensee in such a manner that exposure to such material and to radiation from such material, when added to exposures to unlicensed radioactive material and to other unlicensed sources of radiation in the possession of the licensee, and to radiation therefrom, does not exceed the standards of radiation protection prescribed in the regulations in this part.

35 FR 18385

(c) In accordance with recommendations of the Federal Radiation Council, approved by the President, persons engaged in activities under licenses issued by the Nuclear Regulatory Commission pursuant to the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974 should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures, and releases of radioactive materials in effluents to unrestricted areas, as far below the limits specified in this part as practicable. The term "as far below the limits specified in this part as practicable" means as low as is practicably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety and in relation to the utilization of atomic energy in the public interest.

§ 20.2 Scope.

40 FR 8774

The regulations in this part apply to all persons who receive, possess, use, or transfer material licensed pursuant to the regulations in Parts 30 through 35, 40, or 70 of this chapter, including persons licensed to operate a production or utilization facility pursuant to Part 50 of this chapter.

§ 20.3 Definitions.

(a) As used in this part:

(1) "Act" means the Atomic Energy Act of 1954 (68 Stat. 919) including any amendments thereto;

(2) "Airborne radioactive material" means any radioactive material dispersed in the air in the form of dusts, fumes, mists, vapors, or gases;

(3) "Byproduct material" means any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material;

(4) "Calendar quarter" means not less than 12 consecutive weeks nor more than 14 consecutive weeks. The first calendar quarter of each year shall begin in January and subsequent calendar quarters shall be such that no day is included in more than one calendar quarter or omitted from inclusion within a calendar quarter. No licensee shall change the method observed by him of determining calendar quarters except at the beginning of a calendar year.

(5) "Commission" means the Nuclear Regulatory Commission or its duly authorized representatives;

(6) "Government agency" means any executive department, commission, independent establishment, corporation, wholly or partly owned by the United States of America which is an instrumentality of the United States, or any board, bureau, division, service, office, officer, authority, administration, or other establishment in the executive branch of the Government;

(7) "Individual" means any human being;

25 FR 10914

(8) "Licensed material" means source material, special nuclear material, or by-product material received, possessed, used, or transferred under a general or specific license issued by the Commission pursuant to the regulations in this chapter;

(9) "License" means a license issued under the regulations in Part 30, 40, or 70, of this chapter "Licensee" means the holder of such license;

(10) "Occupational dose" includes exposure of an individual to radiation (i) in a restricted area; or (ii) in the course of employment in which the individual's duties involve exposure to radiation, provided, that "occupational dose" shall not be deemed to include any exposure of an individual to radiation for the purpose of medical diagnosis or medical therapy of such individual.

40 FR 8774

(11) "Person" means (i) any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, Government agency other than the Commission or the Administration (except that the Administration shall be considered a person within the meaning of the regulations in this part to the extent that its facilities and activities are subject to the licensing and related regulatory authority of the Commission pursuant to section 202 of the Energy Reorganization Act of 1974 (88 Stat. 1244)), any State, any foreign government or nation or any political subdivision of any such government or nation, or other entity, and (ii) any legal successor, representative, agent, or agency of the foregoing.

25 FR 10914

(12) "Radiation" means any or all of the following alpha rays, beta rays, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other atomic particles; but not sound or radio waves, or visible, infrared, or ultraviolet light;

(13) "Radioactive material" includes any such material whether or not subject to licensing control by the Commission,

25 FR 13952

(14) "Restricted area" means any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area;

27 FR 5905

(15) "Source material" means (i) uranium or thorium, or any combination thereof, in any physical or chemical form: or (ii) ores which contain by weight one-twentieth of one percent (0.05%) or more of a. uranium, b thorium or c. any combination thereof. Source material does not include special nuclear material.

25 FR 10914

(16) "Special nuclear material" means (i) plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the act, determines to be special nuclear material, but does not include source material; or (ii) any material artificially enriched by any of the foregoing but does not include source material;

25 FR 13952

(17) "Unrestricted area" means any area access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters.

40 FR 8774

(18) "Administration" means the Energy Research and Development Administration or its duly authorized representatives.

(b) Definitions of certain other words and phrases as used in this part are set forth in other sections, including:

(1) "Airborne radioactivity area" defined in § 20.203;

(2) "Radiation area" and "high radiation area" defined in § 20.202;

(3) "Personnel monitoring equipment" defined in § 20.202;

(4) "Survey" defined in § 20.201;

(5) Units of measurement of dose (rad, rem) defined in § 20.4;

(6) Units of measurement of radioactivity defined in § 20.5.

25 FR 10914

§ 20.4 Units of radiation dose.

(a) "Dose," as used in this part, is the quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body. When the regulations in this part specify a dose during a period of time, the dose means the total quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body during such period of time. Several different units of dose are in current use. Definitions of units as used in this part are set forth in paragraphs (b) and (c) of this section.

(b) The rad, as used in this part, is a measure of the dose of any ionizing radiation to body tissues in terms of the energy absorbed per unit mass of the tissue. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue. (One millirad (mrad) = 0.001 rad.)

(c) The rem, as used in this part, is a measure of the dose of any ionizing radiation to body tissue in terms of its estimated biological effect relative to a dose of one roentgen (r) of X-rays. (One millirem (mrem) = 0.001 rem.) The relation of the rem to other dose units depends upon the biological effect under consideration and upon the conditions of irradiation. For the purpose of the regulations in this part, any of the following is considered to be equivalent to a dose of one rem:

(1) A dose of 1 r due to X– or gamma radiation;

(2) A dose of 1 rad due to X–, gamma, or beta radiation;

(3) A dose of 0.1 rad due to neutrons or high energy protons;

(4) A dose of 0.05 rad due to particles heavier than protons and with sufficient energy to reach the lens of the eye;

If it is more convenient to measure the neutron flux, or equivalent, than to determine the neutron dose in rads, as provided in subparagraph (3) of this paragraph, one rem of neutron radiation may, for purposes of the regulations in this part, be assumed to be equivalent to 14 million neutrons per square centimeter incident upon the body; or, if there exists sufficient information to estimate with reasonable accuracy the approximate distribution in energy of the neutrons, the incident number of neutrons per square centimeter equivalent to one rem may be estimated from the following table:

25 FR 10914

NEUTRON FLUX DOSE EQUIVALENTS

Neutron energy (Mev)	Number of neutrons per square centimeter equivalent to a dose of 1 rem (neutrons/cm²)	Average flux to deliver 100 millirem in 40 hours (neutrons/cm² per sec.)
Thermal	970×10^6	670
0.0001	720×10^6	500
0.005	820×10^6	570
0.02	400×10^6	280
0.1	120×10^6	80
0.5	43×10^6	30
1.0	26×10^6	18
2.5	29×10^6	20
5.0	26×10^6	18
7.5	24×10^6	17
10	24×10^6	17
10 to 30	14×10^6	10

(d) For determining exposures to X or gamma rays up to 3 Mev, the dose limits specified in §§ 20.101 to 20.104, inclusive, may be assumed to be equivalent to the "air dose". For the purpose of this part "air dose" means that the dose is measured by a properly calibrated appropriate instrument in air at or near the body surface in the region of highest dosage rate.

38 FR 29314

§ 20.5 Units of radioactivity.

(a) Radioactivity is commonly, and for purposes of the regulations in this part shall be, measured in terms of disintegrations per unit time or in curies. One curie = 3.7×10^{10} disintegrations per second (dps) = 2.2×10^{12} disintegrations per minute (dpm). Commonly used submultiples of the curie are the millicurie and the microcurie:

(1) One millicurie (mCi) [1] = 0.001 curie (Ci) [1] = 3.7×10^7 dps.

(2) One microcurie (μCi) [1] = 0.000001 curie = 3.7×10^4 dps.

(b) For purposes of the regulations in this part, it may be assumed that the

[1] Wherever possible, the appropriate unit should be written out as "curie(s)," "millicurie(s)," or "microcurie(s)," and the abbreviations should not be used.

daughter activity concentrations in the following table are equivalent to an air concentration of 10^{-7} microcuries of Radon 222 per milliliter of air in equilibrium with the daughters RaA, RaB, RaC, and RaC':

Maximum time between collection and measurement (hours)[3]	Alpha-emitting daughter activity collected per milliliter of air	
	Microcuries/cc	Total alpha disintegrations per minute per cc.
0.5	7.2×10^{-8}	0.16
1	4.5×10^{-8}	0.10
2	1.3×10^{-8}	0.028
3	0.3×10^{-8}	0.0092

(c) *

25 FR 10914

§ 20.6 Interpretations.

Except as specifically authorized by the Commission in writing, no interpretation of the meaning of the regulations in this part by any officer or employee of the Commission other than a written interpretation by the General Counsel will be recognized to be binding upon the Commission.

40 FR 8774

§ 20.7 Communications.

Except where otherwise specified in this part, all communications and reports concerning the regulations in this part should be addressed to the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555. Communications, reports, and applications may be delivered in person at the Commission's offices at 1717 H Street NW., Washington, D.C.; or at 7920 Norfolk Avenue, Bethesda, Maryland.

** PERMISSIBLE DOSES, LEVELS, AND CONCENTRATIONS

25 FR 10914

§ 20.101 Exposure of individuals to radiation in restricted areas.

(a) Except as provided in paragraph (b) of this section, no licensee shall possess, use, or transfer licensed material in such a manner as to cause any individual in a restricted area to receive in any period of one calendar quarter from radioactive material and other sources of radiation in the licensee's possession a dose in excess of the limits specified in the following table:

Rems per calendar quarter

1. Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	1¼
2. Hands and forearms; feet and ankles	18¾
3. Skin of whole body	7½

(b) A licensee may permit an individual in a restricted area to receive a dose to the whole body greater than that permitted under paragraph (a) of this section, provided:

(1) During any calendar quarter the dose to the whole body from radioactive material and other sources of radiation in the licensee's possession shall not exceed 3 rems; and

(2) The dose to the whole body, when added to the accumulated occupational dose to the whole body, shall not exceed 5 (N–18) rems where "N" equals the individual's age in years at his last birthday; and

(3) The licensee has determined the individual's accumulated occupational dose to the whole body on Form NRC-4, or on a clear and legible record containing all the information required in that form; and has otherwise complied with the requirements of § 20.102. As used in paragraph (b), "Dose to the whole body" shall be deemed to include any dose to the whole body, gonads, active blood-forming organs, head and trunk, or lens of eye.

25 FR 10914

§ 20.102 Determination of accumulated dose.

(a) This section contains requirements which must be satisfied by licensees who propose, pursuant to paragraph (b) of § 20.101, to permit individuals in a restricted area to receive exposure to radiation in excess of the limits specified in paragraph (a) of § 20.101.

(b) Before permitting any individual in a restricted area to receive exposure to radiation in excess of the limits specified in paragraph (a) of § 20.101, each licensee shall:

(1) Obtain a certificate on Form NRC-4, or on a clear and legible record containing all the information required in that form, signed by the individual showing each period of time after the individual attained the age of 18 in which the individual received an occupational dose of radiation; and

(2) Calculate on Form NRC-4 in accordance with the instructions appearing therein, or on a clear and legible record containing all the information required in that form, the previously accumulated occupational dose received by the individual and the additional dose allowed for that individual under § 20.101(b).

(c)(1) In the preparation of Form NRC-4, or a clear and legible record containing all the information required in that form, the licensee shall make a reasonable effort to obtain reports of the individual's previously accumulated occupational dose. For each period for which the licensee obtains such reports, the licensee shall use the dose shown in the report in preparing the form. In any case where a licensee is unable to obtain reports of the individual's occupational dose for a previous complete calendar quarter, it shall be assumed that the individual has received the occupational dose specified in whichever of the following columns apply:

Part of body	Column 1 Assumed exposure in rems for calendar quarters prior to Jan. 1, 1961	Column 2 Assumed exposure in rems for calendar quarters beginning on or after Jan. 1, 1961
Whole body, gonads, active blood-forming organs, head and trunk, lens of eye.	3¾	1¼

(2) The licensee shall retain and preserve records used in preparing Form NRC-4.

If calculation of the individual's accumulated occupational dose for all periods prior to January 1, 1961 yields a result higher than the applicable accumulated dose value for the individual as of that date, as specified in paragraph (b) of § 20.101, the excess may be disregarded.

§ 20.103 Exposure of individuals to concentrations of radioactive material in restricted areas.

(a) No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual in a restricted area to be exposed to airborne radioactive material possessed by the licensee in an average concentration in excess of the limits specified in Appendix B, Table I, of this part. "Expose" as used in this section means that the individual is present in an airborne concentration. No allowance shall be made for the use of protective clothing or equipment, or particle size, except as authorized by the Commission pursuant to paragraph (c) of this section.

(b) The limits given in Appendix B, Table I, of this part are based upon exposure to the concentrations specified for forty hours in any period of seven consecutive days. In any such period where the number of hours of exposure is less than forty, the limits specified in the table may be increased proportionately. In any such period where the number of hours of exposure is greater than forty, the limits specified in the table shall be decreased proportionately.

(c)(1) Except as authorized by the Commission pursuant to this paragraph, no allowance shall be made for particle size or the use of protective clothing or equipment in determining whether an individual is exposed to an airborne concentration in excess of the limits specified in Appendix B, Table I.

(2) The Commission may authorize a licensee to expose an individual in a restricted area to airborne concentrations in excess of the limits specified in Appendix B, Table I, upon receipt of an application demonstrating that the concentration is composed in whole or in part of particles of such size that such particles are not respirable; and that the individual will not inhale the concentrations in excess of the limits established in Appendix B, Table I. Each application under this subparagraph shall include an analysis of particle sizes in the concentrations; and a description

[3] The duration of sample collection and the duration of measurement should be sufficiently short compared to the time between collection and measurement, as not to have a statistically significant effect upon the results.

* Deleted 39 FR 23990.

** Amended 36 FR 1466.

of the methods used in determining the particle sizes.

(3) The Commission may authorize a licensee to expose an individual in a restricted area to airborne concentrations in excess of the limits specified in Appendix B, Table I, upon receipt of an application demonstrating that the individual will wear appropriate protective equipment and that the individual will not inhale, ingest or absorb quantities of radioactive material in excess of those which might otherwise be permitted under this part for employees in restricted areas during a 40-hour week. Each application under this subparagraph shall contain the following information:

26 FR 1094

(i) A description of the protective equipment to be employed, including the efficiency of the equipment for the material involved;

(ii) Procedures for the fitting, maintenance and cleaning of the protective equipment; and

(iii) Procedures governing the use of the protective equipment, including supervisory procedures and length of time the equipment will be used by the individuals in each work week. The proposed periods for use of the equipment by any individual should not be of such duration as would discourage observance by the individual of the proposed procedures; and

(iv) The average concentrations present in the areas occupied by employees.

25 FR 10914

§ 20.104 Exposure of minors.

(a) No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual within a restricted area who is under 18 years of age, to receive in any period of one calendar quarter from radioactive material and other sources of radiation in the licensee's possession a dose in excess of 10 percent of the limits specified in the table in paragraph (a) of § 20.101.

(b) No licensee shall possess, use or transfer licensed material in such a manner as to cause any individual within a restricted area, who is under 18 years of age to be exposed to airborne radioactive material possessed by the licensee in an average concentration in excess of the limits specified in Appendix B, Table II of this part. For purposes of this paragraph, concentrations may be averaged over periods not greater than a week.

29 FR 1443

(c) The provisions of paragraph (c) of § 20.103, shall apply to exposures subject to paragraph (b) of this section.

§ 20.105 Permissible levels of radiation in unrestricted areas.

(a) There may be included in any application for a license or for amendment of a license proposed limits upon levels of radiation in unrestricted areas resulting from the applicant's possession or use of radioactive material and other sources of radiation. Such applications should include information as to anticipated average radiation levels and anticipated occupancy times for each unrestricted area involved. The Commission will approve the proposed limits if the applicant demonstrates that the proposed limits are not likely to cause any individual to receive a dose to the whole body in any period of one calendar year in excess of 0.5 rem.

(b) Except as authorized by the Commission pursuant to paragraph (a) of this section, no licensee shall possess, use or transfer licensed material in such a manner as to create in any unrestricted area from radioactive material and other sources of radiation in his possession:

26 FR 1094

(1) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of two millirems in any one hour, or

(2) Radiation levels which, if an individual were continuously present in the area, could result in his receiving a dose in excess of 100 millirems in any seven consecutive days.

§ 20.106 Radioactivity in effluents to unrestricted areas.

(a) A licensee shall not possess, use, or transfer licensed material so as to release to an unrestricted area radioactive material in concentrations which exceed the limits specified in Appendix "B", Table II of this part, except as authorized pursuant to § 20.302 or paragraph (b) of this section. For purposes of this section concentrations may be averaged over a period not greater than one year.

(b) An application for a license or amendment may include proposed limits higher than those specified in paragraph (a) of this section. The Commission will approve the proposed limits if the applicant demonstrates:

(1) That the applicant has made a reasonable effort to minimize the radioactivity contained in effluents to unrestricted areas; and

(2) That it is not likely that radioactive material discharged in the effluent would result in the exposure of an individual to concentrations of radioactive material in air or water exceeding the limits specified in Appendix "B", Table II of this part.

29 FR 14434

(c) An application for higher limits pursuant to paragraph (b) of this section shall include information demonstrating that the applicant has made a reasonable effort to minimize the radioactivity discharged in effluents to unrestricted areas, and shall include, as pertinent:

(1) Information as to flow rates, total volume of effluent, peak concentration of each radionuclide in the effluent, and concentration of each radionuclide in the effluent averaged over a period of one year at the point where the effluent leaves a stack, tube, pipe, or similar conduit;

(2) A description of the properties of the effluents, including:

(i) chemical composition;

(ii) physical characteristics, including suspended solids content in liquid effluents, and nature of gas or aerosol for air effluents;

(iii) the hydrogen ion concentrations (p^H) of liquid effluents; and

(iv) the size range of particulates in effluents released into air.

(3) A description of the anticipated human occupancy in the unrestricted area where the highest concentration of radioactive material from the effluent is expected, and, in the case of a river or stream, a description of water uses downstream from the point of release of the effluent.

(4) Information as to the highest concentration of each radionuclide in an unrestricted area, including anticipated concentrations averaged over a period of one year:

(i) In air at any point of human occupancy; or

(ii) In water at points of use downstream from the point of release of the effluent.

(5) The background concentration of radionuclides in the receiving river or stream prior to the release of liquid effluent.

(6) A description of the environmental monitoring equipment, including sensitivity of the system, and procedures and calculations to determine concentrations of radionuclides in the unrestricted area and possible reconcentrations of radionuclides.

(7) A description of the waste treatment facilities and procedures used to reduce the concentration of radionuclides in effluents prior to their release.

29 FR 14434

(d) For the purposes of this section the concentration limits in Appendix "B", Table II of this part shall apply at the boundary of the restricted area. The concentration of radioactive material discharged through a stack, pipe or similar conduit may be determined with respect to the point where the material leaves the conduit. If the conduit discharges within the restricted area, the concentration at the boundary may be determined by applying appropriate factors for dilution, dispersion, or decay between the point of discharge and the boundary.

(e) In addition to limiting concentrations in effluent streams, the Commission may limit quantities of radioactive materials released in air or water during a specified period of time if it appears that the daily intake of radioactive material from air, water, or food by a suitable sample of an exposed population group, averaged over a period not exceeding one year, would otherwise exceed the daily intake resulting from continuous exposure to air or water containing one-third the concentration of radioactive materials specified in Appendix "B", Table II of this part.

(f) The provisions of this section do not apply to disposal of radioactive material into sanitary sewerage systems, which is governed by § 20.303

§ 20.107 Medical diagnosis and therapy.

Nothing in the regulations in this part shall be interpreted as limiting the intentional exposure of patients to radiation for the purpose of medical diagnosis or medical therapy.

25 FR 10914

§ 20.108 Orders requiring furnishing of bio-assay services.

Where necessary or desirable in order to aid in determining the extent of an

individual's exposure to concentrations of radioactive material, the Commission may incorporate appropriate provisions in any license, directing the licensee to make available to the individual appropriate bio-assay services and to furnish a copy of the reports of such services to the Commission.

PRECAUTIONARY PROCEDURES

§ 20.201 Surveys.

(a) As used in the regulations in this part, "survey" means an evaluation of the radiation hazards incident to the production, use, release, disposal, or presence of radioactive materials or other sources of radiation under a specific set of conditions. When appropriate, such evaluation includes a physical survey of the location of materials and equipment, and measurements of levels of radiation or concentrations of radioactive material present.

(b) Each licensee shall make or cause to be made such surveys as may be necessary for him to comply with the regulations in this part.

§ 20.202 Personnel monitoring.

(a) Each licensee shall supply appropriate personnel monitoring equipment to, and shall require the use of such equipment by:

(1) Each individual who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 25 percent of the applicable value specified in paragraph (a) of § 20.101

35 FR 10914

(2) Each individual under 18 years of age who enters a restricted area under such circumstances that he receives, or is likely to receive, a dose in any calendar quarter in excess of 5 percent of the applicable value specified in paragraph (a) of § 20.101.

(3) Each individual who enters a high radiation area.

(b) As used in this part,

(1) "Personnel monitoring equipment" means devices designed to be worn or carried by an individual for the purpose of measuring the dose received (e. g., film badges, pocket chambers, pocket dosimeters, film rings, etc.);

(2) "Radiation area" means any area, accessible to personnel, in which there exists radiation, originating in whole or in part within licensed material, at such levels that a major portion of the body could receive in any one hour a dose in excess of 5 millirem, or in any 5 consecutive days a dose in excess of 100 millirems;

(3) "High radiation area" means any area, accessible to personnel, in which there exists radiation originating in whole or in part within licensed material at such levels that a major portion of the body could receive in any one hour a dose in excess of 100 millirem.

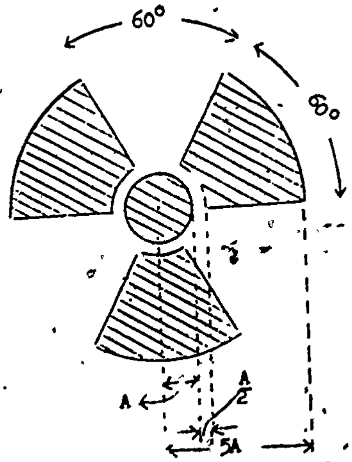
35 FR 5033

§ 20.203 Caution signs, labels, signals, and controls.

(a) *General.* (1) Except as otherwise authorized by the Commission, symbols prescribed by this section shall use the conventional radiation caution colors (magenta or purple on yellow background). The symbol prescribed by this section is the conventional three-bladed design:

RADIATION SYMBOL

1. Cross-hatched area is to be magenta or purple.
2. Background is to be yellow.



(2) In addition to the contents of signs and labels prescribed in this section, licensees may provide on or near such signs and labels any additional information which may be appropriate in aiding individuals to minimize exposure to radiation or to radioactive material.

(b) *Radiation areas.* Each radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
RADIATION AREA

(c) *High radiation areas.* (1) Each high radiation area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
HIGH RADIATION AREA

(2) Each entrance or access point to a high radiation area shall be:

(i) Equipped with a control device which shall cause the level of radiation to be reduced below that at which an individual might receive a dose of 100 millirems in 1 hour upon entry into the area; or

(ii) Equipped with a control device which shall energize a conspicuous visible or audible alarm signal in such a manner that the individual entering the high radiation area and the licensee or a supervisor of the activity are made aware of the entry; or

(iii) Maintained locked except during periods when access to the area is required, with positive control over each individual entry.

(3) The controls required by subparagraph (2) of this paragraph shall be established in such a way that no individual will be prevented from leaving a high radiation area.

(4) In the case of a high radiation area established for a period of 30 days or less, direct surveillance to prevent unauthorized entry may be substituted for the controls required by subparagraph (2) of this paragraph.

(5) Any licensee, or applicant for a license, may apply to the Commission for approval of methods not included in subparagraphs (2) and (4) of this paragraph for controlling access to high radiation areas. The Commission will approve the proposed alternatives if the licensee or applicant demonstrates that the alternative methods of control will prevent unauthorized entry into a high radiation area, and that the requirement of subparagraph (3) of this paragraph is met.

35 FR 5033

(d) *Airborne radioactivity areas.* (1) As used in the regulations in this part, "airborne radioactivity area" means (i) any room, enclosure, or operating area in which airborne radioactive materials, composed wholly or partly of licensed material, exist in concentrations in excess of the amounts specified in Appendix B, Table I, Column 1 of this part; or (ii) any room, enclosure, or operating area in which airborne radioactive material composed wholly or partly of licensed material exists in concentrations which, averaged over the number of hours in any week during which individuals are in the area, exceed 25 percent of the amounts specified in Appendix B, Table I, Column 1 of this part.

(2) Each airborne radioactivity area shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
AIRBORNE RADIOACTIVITY AREA

(e) *Additional requirements.* (1) Each area or room in which licensed material is used or stored and which contains any radioactive material (other than natural uranium or thorium) in an amount exceeding 10 times the quantity of such material specified in Appendix C of this part shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
RADIOACTIVE MATERIAL(S)

(2) Each area or room in which natural uranium or thorium is used or stored in an amount exceeding one-hundred times the quantity specified in Appendix C of this part shall be conspicuously posted with a sign or signs bearing the radiation caution symbol and the words:

CAUTION[1]
RADIOACTIVE MATERIAL(S)

(f) *Containers.* (1) Except as provided in subparagraph (3) of this paragraph, each container of licensed mate-

[1] Or "Danger"

rial shall bear a durable, clearly visible label identifying the radioactive contents.

(2) A label required pursuant to subparagraph (1) of this paragraph shall bear the radiation caution symbol and the words "CAUTION, RADIOACTIVE MATERIAL" or "DANGER, RADIOACTIVE MATERIAL". It shall also provide sufficient information[1] to permit individuals handling or using the containers, or working in the vicinity thereof, to take precautions to avoid or minimize exposures.

(3) Notwithstanding the provisions of subparagraph (1) of this paragraph, labeling is not required:

(i) For containers that do not contain licensed materials in quantities greater than the applicable quantities listed in Appendix C of this part.

(ii) For containers containing only natural uranium or thorium in quantities no greater than 10 times the applicable quantities listed in Appendix C of this part.

(iii) For containers that do not contain licensed materials in concentrations greater than the applicable concentrations listed in Column 2, Table I, Appendix B of this part.

(iv) For containers when they are attended by an individual who takes the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established by the regulations in this part.

(v) For containers when they are in transport and packaged and labeled in accordance with regulations of the Department of Transportation.

(vi) For containers which are accessible[2] only to individuals authorized to handle or use them, or to work in the vicinity thereof, provided that the contents are identified to such individuals by a readily available written record.

(vii) For manufacturing or process equipment, such as nuclear reactors, reactor components, piping, and tanks.

31 FR 10914

§ 20.204 Same: exceptions.

Notwithstanding the provisions of § 20.203,

(a) A room or area is not required to be posted with a caution sign because of the presence of a sealed source provided the radiation level twelve inches from the surface of the source container or housing does not exceed five millirem per hour.

25 FR 10914

(b) Rooms or other areas in hospitals are not required to be posted with caution signs, and control of entrance or access thereto pursuant to § 20.203(c) is not required, because of the presence of patients containing byproduct material provided that there are personnel in attendance who will take the precautions necessary to prevent the exposure of any individual to radiation or radioactive material in excess of the limits established in the regulations in this part.

35 FR 5033

(c) Caution signs are not required to be posted at areas or rooms containing radioactive materials for periods of less than eight hours provided that (1) the materials are constantly attended during such periods by an individual who shall take the precautions necessary to prevent the exposure of any individual to radiation or radioactive materials in excess of the limits established in the regulations in this part and; (2) such area or room is subject to the licensee's control.

25 FR 10914

(d) A room or other area is not required to be posted with a caution sign, and control is not required for each entrance or access point to a room or other area which is a high radiation area solely because of the presence of radioactive materials prepared for transport and packaged and labeled in accordance with regulations of the Department of Transportation.

35 FR 5033

§ 20.205 Procedures for picking up, receiving, and opening packages.

(a)(1) Each licensee who expects to receive a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section shall:

(i) If the package is to be delivered to the licensee's facility by the carrier, make arrangements to receive the package when it is offered for delivery by the carrier; or

(ii) If the package is to be picked up by the licensee at the carrier's terminal, make arrangements to receive notification from the carrier of the arrival of the package, at the time of arrival.

(2) Each licensee who picks up a package of radioactive material from a carrier's terminal shall pick up the package expeditiously upon receipt of notification from the carrier of its arrival.

(b)(1) Each licensee, upon receipt of a package of radioactive material, shall monitor the external surfaces of the package for radioactive contamination caused by leakage of the radioactive contents, except:

(i) Packages containing no more than the exempt quantity specified in the table in this paragraph;

(ii) Packages containing no more than 10 millicuries of radioactive material consisting solely of tritium, carbon-14, sulfur-35, or iodine-125;

(iii) Packages containing only radioactive material as gases or in special form;

(iv) Packages containing only radioactive material in other than liquid form (including Mo-99/Tc-99m generators) and not exceeding the Type A quantity limit specified in the table in this paragraph; and

(v) Packages containing only radionuclides with half-lives of less than 30 days and a total quantity of no more than 100 millicuries.

The monitoring shall be performed as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or eighteen hours if received after normal working hours.

(2) If removable radioactive contamination in excess of 0.01 microcuries (22,000 disintegrations per minute) per 100 square centimeters of package surface is found on the external surfaces of the package, the licensee shall immediately notify the final delivering carrier and, by telephone and telegraph, the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office shown in Appendix D.

TABLE OF EXEMPT AND TYPE A QUANTITIES

Transport group[1]	Exempt quantity limit (in millicuries)	Type A quantity limit (in curies)
I	.01	0.001
II	0.1	0.050
III	1	3
IV	1	20
V	1	20
VI	1	1000
VII	25,000	1000
Special Form	1	20

(c)(1) Each licensee, upon receipt of a package containing quantities of radioactive material in excess of the Type A quantities specified in paragraph (b) of this section, other than those transported by exclusive use vehicle, shall monitor the radiation levels external to the package. The package shall be monitored as soon as practicable after receipt, but no later than three hours after the package is received at the licensee's facility if received during the licensee's normal working hours, or 18 hours if received after normal working hours.

(2) If radiation levels are found on the external surface of the package in excess of 200 millirem per hour, or at three feet from the external surface of the package in excess of 10 millirem per hour, the licensee shall immediately notify, by telephone and telegraph, the final delivering carrier and the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office shown in Appendix D.

(d) Each licensee shall establish and maintain procedures for safely opening packages in which licensed material is received, and shall assure that such procedures are followed and that due consideration is given to special instructions for the type of package being opened.

39 FR 17972

§ 20.206 Instruction of personnel.

Instructions required for individuals working in or frequenting any portion of a restricted area are specified in § 19.12 of this chapter.

38 FR 22220

[1] As appropriate, the information will include radiation levels, kinds of material, estimate of activity, date for which activity is estimated, mass enrichment, etc.

[2] For example, containers in locations such as water-filled canals, storage vaults, or hot cells.

• Amended 34 FR 19546.

[1] The definitions of "transport group" and "special form" are specified in § 71.4 of this chapter.

§ 20.207 Storage of licensed materials.

Licensed materials stored in an unrestricted area shall be secured against unauthorized removal from the place of storage.

WASTE DISPOSAL

§ 20.301 General requirement.

No licensee shall dispose of licensed material except:

(a) By transfer to an authorized recipient as provided in the regulations in Part 30, 40, or 70 of this chapter, whichever may be applicable; or

(b) As authorized pursuant to § 20.302; or

(c) As provided in § 20.303 or § 20.304, applicable respectively to the disposal of licensed material by release into sanitary sewerage systems or burial in soil, or in § 20.106 (Radioactivity in Effluents to Unrestricted Areas).

25 FR 10914

§ 20.302 Method for obtaining approval of proposed disposal procedures.

*(a) Any licensee or applicant for a license may apply to the Commission for approval of proposed procedures to dispose of licensed material in a manner not otherwise authorized in the regulations in this chapter. Each application should include a description of the licensed material and any other radioactive material involved, including the quantities and kinds of such material and the levels of radioactivity involved, and the proposed manner and conditions of disposal. The application should also include an analysis and evaluation of pertinent information as to the nature of the environment, including topographical, geological, meteorological, and hydrological characteristics; usage of ground and surface waters in the general area; the nature and location of other potentially affected facilities; and procedures to be observed to minimize the risk of unexpected or hazardous exposures.

26 FR 352

*(b) The Commission will not approve any application for a license to receive licensed material from other persons for disposal on land not owned by the Federal government or by a State government.

36 FR 23138

(c) The Commission will not approve any application for a license for disposal of licensed material at sea unless the applicant shows that sea disposal offers less harm to man or the environment than other practical alternative methods of disposal.

25 FR 10914

§ 20.303 Disposal by release into sanitary sewerage systems.

No licensee shall discharge licensed material into a sanitary sewerage system unless:

(a) It is readily soluble or dispersible in water; and

(b) The quantity of any licensed or other radioactive material released into the system by the licensee in any one day does not exceed the larger of subparagraphs (1) or (2) of this paragraph:

38 FR 8810

(1) The quantity which, if diluted by the average daily quantity of sewage released into the sewer by the licensee, will result in an average concentration equal to the limits specified in Appendix B, Table I, Column 2 of this part; or

(2) Ten times the quantity of such material specified in Appendix C of this part; and

(c) The quantity of any licensed or other radioactive material released in any one month, if diluted by the average monthly quantity of water released by the licensee, will not result in an average concentration exceeding the limits specified in Appendix B, Table I, Column 2 of this part; and

(d) The gross quantity of licensed and other radioactive material released into the sewerage system by the licensee does not exceed one curie per year.

Excreta from individuals undergoing medical diagnosis or therapy with radioactive material shall be exempt from any limitations contained in this section.

25 FR 10914

§ 20.304 Disposal by burial in soil.

No licensee shall dispose of licensed material by burial in soil unless:

(a) The total quantity of licensed and other radioactive materials buried at any one location and time does not exceed, at the time of burial, 1,000 times the amount specified in Appendix C of this part; and

(b) Burial is at a minimum depth of four feet; and

(c) Successive burials are separated by distances of at least six feet and not more than 12 burials are made in any year.

§ 20.305 Treatment or disposal by incineration.

No licensee shall treat or dispose of licensed material by incineration except as specifically approved by the Commission pursuant to §§ 20.106(b) and 20.302.

RECORDS, REPORTS, AND NOTIFICATION

§ 20.401 Records of surveys, radiation monitoring, and disposal.

(a) Each licensee shall maintain records showing the radiation exposures of all individuals for whom personnel monitoring is required under § 20.202 of the regulations in this part. Such records shall be kept on Form NRC-5, in accordance with the instructions contained in that form or on clear and legible records containing all the information required by Form NRC-5. The doses entered on the forms or records shall be for periods of time not exceeding one calendar quarter.

25 FR 17972

(b) Each licensee shall maintain records in the same units used in this part, showing the results of surveys required by § 20.201(b), monitoring required by §§ 20.205(b) and 20.205(c), and disposals made under §§ 20.302, 20.303, and 20.304.

38 FR 8810

(c) Records of individual exposure to radiation and to radioactive material which must be maintained pursuant to the provisions of paragraph (a) of this section and records of bio-assays, including results of whole body counting examinations, made pursuant to § 20.108 shall be preserved indefinitely or until the Commission authorizes their disposal. Records which must be maintained pursuant to this part may be maintained in the form of microfilms.

34 FR 7500

§ 20.402 Reports of theft or loss of licensed material.

(a) Each licensee shall report by telephone and telegraph to the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix D, immediately after its occurrence becomes known to the licensee, any loss or theft of licensed material in such quantities and under such circumstances that it appears to the licensee that a substantial hazard may result to persons in unrestricted areas.

(b) Each licensee who is required to make a telephonic and telegraphic report pursuant to paragraph (a) of this section shall, within 30 days after he learns of the loss or theft, make a report in writing to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, with a copy to the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix D, setting forth the following information:

(1) A description of the licensed material involved, including kind, quantity, chemical, and physical form;

(2) A description of the circumstances under which the loss or theft occurred;

(3) A statement of disposition or probable disposition of the licensed material involved;

(4) Radiation exposures to individuals, circumstances under which the exposures occurred, and the extent of possible hazard to persons in unrestricted areas;

(5) Actions which have been taken, or will be taken, to recover the material; and

(6) Procedures or measures which have been or will be adopted to prevent a recurrence of the loss or theft of licensed material.

(c) Subsequent to filing the written report the licensee shall also report any substantive additional information on the loss or theft which becomes available to the licensee, within 30 days after he learns of such information.

(d) Any report filed with the Commission pursuant to this section shall be so prepared that names of individuals who may have received exposure to radiation are stated in a separate part of the report.

27 FR 5905

§ 20.403 Notifications of incidents.

(a) *Immediate notification.* Each licensee shall immediately notify the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office

* Redesignated 36 FR 23138.

shown in Appendix D by telephone and telegraph of any incident involving byproduct, source or special nuclear material possessed by him and which may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 25 rems or more of radiation; exposure of the skin of the whole body of any individual of 150 rems or more of radiation, or exposure of the feet, ankles, hands or forearms of any individual to 375 rems or more of radiation; or

(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 5,000 times the limits specified for such materials in Appendix B, Table II; or

(3) A loss of one working week or more of the operation of any facilities affected; or

(4) Damage to property in excess of $100,000.

27 FR 5905

(b) *Twenty-four hour notification* Each licensee shall within 24 hours notify the Director of the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix D by telephone and telegraph of any incident involving licensed material possessed by him and which may have caused or threatens to cause:

(1) Exposure of the whole body of any individual to 5 rems or more of radiation; exposure of the skin of the whole body of any individual to 30 rems or more of radiation; or exposure of the feet, ankles, hands, or forearms to 75 rems or more of radiation; or

(2) The release of radioactive material in concentrations which, if averaged over a period of 24 hours, would exceed 500 times the limits specified for such materials in Appendix B, Table II; or

(3) A loss of one day or more of the operation of any facilities affected; or

(4) Damage to property in excess of $1,000.

28 FR 6822

(c) Any report filed with the Commission pursuant to this section shall be prepared so that names of individuals who have received exposure to radiation will be stated in a separate part of the report.

§ 20.404 †

§ 20.405 Reports of overexposures and excessive levels and concentrations.

27 FR 5905

(a) In addition to any notification required by § 20.403, each licensee shall make a report in writing within 30 days to the Director of Inspection and Enforcement, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, with a copy to the appropriate Nuclear Regulatory Commission Inspection and Enforcement Regional Office listed in Appendix D, of (1) each exposure of an individual to radiation or concentrations of radioactive material in excess of any applicable limit in this part or in the licensee's license; (2) any incident for which notification is required by § 20.403; and (3) levels of radiation or concentrations of radioactive material (not involving excessive exposure of any individual) in an unrestricted area in excess of ten times any applicable limit set forth in this part or in the licensee's license.

35 FR 15067

Each report required under this paragraph shall describe the extent of exposure of persons to radiation or to radioactive material, including estimates of each individual's exposure as required by paragraph (b) of this section; levels of radiation and concentrations of radioactive material involved; the cause of the exposure, levels or concentrations; and corrective steps taken or planned to assure against a recurrence.

(b) Any report filed with the Commission pursuant to this section shall include for each individual exposed the name, social security number, and date of birth; and an estimate of the individual's exposure. The report shall be prepared so that this information is stated in a separate part of the report.

(c) †

§ 20.406 †

§ 20.407 Personnel exposure and monitoring reports.

39 FR 1000

(a) This section applies to each person licensed by the Commission or the Atomic Energy Commission to:

(1) Operate a nuclear reactor designed to produce electrical or heat energy pursuant to § 50.21(b) or § 50.22 of this chapter or a testing facility as defined in § 50.2(r) of this chapter;

(2) Possess or use byproduct material for purposes of radiography pursuant to Parts 30 and 34 of this chapter;

(3) Possess or use at any one time, for purposes of fuel processing fabrication, or reprocessing, special nuclear material in a quantity exceeding 5,000 grams of contained uranium-235, uranium-233, or plutonium or any combination thereof pursuant to Part 70 of this chapter; or

(4) Possess or use at any one time, for processing or manufacturing for distribution pursuant to Part 30, 32, or 33 of this chapter, byproduct material in quantities exceeding anyone of the following quantities:

Radionuclide [1]	*Quantity in curies*
Cesium-137	1
Cobalt-60	1
Gold-198	100
Iodine-131	1
Iridium-192	10
Krypton-85	1,000
Promethium-147	10
Technetium-99m	1,000

34 FR 5254

(b) Each person described in paragraph (a) of this section shall, within the first quarter of each calendar year, submit to the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, the following reports, applicable to the described licensed activities covering the preceding calendar year: [2]

(1) A report of either (i) the total number of individuals for whom personnel monitoring was required under §§ 20.202(a) or 34.33(a) of this chapter, during the calendar year, or (ii) the total number of individuals for whom personnel monitoring was provided during the calendar year; *Provided*, that such total includes at least the number of individuals required to be reported under paragraph (b)(1)(i) of this section. The report shall indicate whether it is submitted in accordance with paragraph (b)(1)(i) or (ii) of this section.

(2) A statistical summary report of the personnel monitoring information recorded by the licensee for individuals for whom personnel monitoring was either required or provided, as described in § 20.407(b)(1), indicating the number of individuals whose total whole body exposure recorded during the previous calendar year was in each of the following estimated exposure ranges:

39 FR 1000

Estimated Whole Body Exposure Range (Rems) [3]	*Number of individuals in each range*
No measurable exposure	
Measurable exposure less than 0.1	
0.1 to 0.25	
0.25 to 0.5	
0.5 to 0.75	
0.75 to 1	
1 to 2	
2 to 3	
3 to 4	
4 to 5	
5 to 6	
6 to 7	
7 to 8	
8 to 9	
9 to 10	
10 to 11	
11 to 12	
12+	

The low exposure range data are required in order to obtain better information about the exposures actually recorded. This section does not require improved measurements.

§ 20.408 Reports of personnel exposure on termination of employment or work.

When an individual terminates employment with a licensee subject to § 20.407, or an individual assigned to work in such a licensee's facility, but not employed by the licensee, completes his work assignment in the licensee's facility, the licensee shall furnish • to the Executive Director for Operations, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555, a report of the individual's exposure to radiation and radioactive material, incurred during the

† Deleted 38 FR 22220.

[1] The Commission may require, as a license condition, or by rule, regulation, or order pursuant to § 20.502, reports from licensees who are licensed to use radionuclides not on this list, in quantities sufficient to cause comparable radiation levels.

† Deleted 38 FR 22220.

[2] A licensee whose license expires or terminates prior to, or on the last day of the calendar year, shall submit reports at the expiration or termination of the license, covering that part of the year during which the license was in effect.

[3] Individual values exactly equal to the values separating Exposure Ranges shall be reported in the higher range.

• Amended 38 FR 22220.

period of employment or work assignment in the licensee's facility, containing information recorded by the licensee pursuant to §§ 20.401(a) and 20.108. Such report shall be furnished within 30 days after the exposure of the individual has been determined by the licensee or 90 days after the date of termination of employment or work assignment, whichever is earlier.

34 FR 5264

§ 20.409 Notifications and reports to individuals.

(a) Requirements for notifications and reports to individuals of exposure to radiation or radioactive material are specified in § 19.13 of this chapter.

(b) When a licensee is required pursuant to §§ 20.405 or 20.408 to report to the Commission any exposure of an individual to radiation or radioactive material, the licensee shall also notify the individual. Such notice shall be transmitted at a time not later than the transmittal to the Commission, and shall comply with the provisions of § 19.13(a) of this chapter.

38 FR 22220

EXCEPTIONS AND ADDITIONAL REQUIREMENTS

§ 20.501 Applications for exemptions.

The Commission may, upon application by any licensee or upon its own initiative, grant such exemptions from the requirements of the regulations in this part as it determines are authorized by law and will not result in undue hazard to life or property.

§ 20.502 Additional requirements.

The Commission may, by rule, regulation, or order, impose upon any licensee such requirements, in addition to those established in the regulations in this part, as it deems appropriate or necessary to protect health or to minimize danger to life or property.

25 FR 10914

§ 20.601 Violations.

An injunction or other court order may be obtained prohibiting any violation of any provision of the Atomic Energy Act of 1954, as amended, or Title II of the Energy Reorganization Act of 1974, or any regulation or order issued thereunder. A court order may be obtained for the payment of a civil penalty imposed pursuant to section 234 of the Act for violation of section 53, 57, 62, 63, 81, 82, 101, 103, 104, 107, or 109 of the Act, or section 206 of the Energy Reorganization Act of 1974, or any rule, regulation, or order issued thereunder, or any term, condition, or limitation of any license issued thereunder, or for any violation for which a license may be revoked under section 186 of the Act. Any person who willfully violates any provision of the Act or any regulation or order issued thereunder may be guilty of a crime and, upon conviction, may be punished by fine or imprisonment or both, as provided by law.

40 FR 8774

APPENDIX A [Reserved]

APPENDIX B

Concentrations in Air and Water Above Natural Background

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Actinium (89)	Ac 227	S	2×10^{-12}	6×10^{-5}	8×10^{-14}	2×10^{-6}
		I	3×10^{-11}	9×10^{-3}	9×10^{-13}	3×10^{-4}
	Ac 228	S	8×10^{-8}	3×10^{-3}	3×10^{-9}	9×10^{-5}
		I	2×10^{-8}	3×10^{-3}	6×10^{-10}	9×10^{-5}
Americium (95)	Am 241	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		* I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Am 242m	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	3×10^{-10}	3×10^{-3}	9×10^{-12}	9×10^{-5}
	Am 242	S	4×10^{-8}	4×10^{-3}	1×10^{-9}	1×10^{-4}
		I	5×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
	Am 243	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Am 244	S	4×10^{-6}	1×10^{-1}	1×10^{-7}	5×10^{-3}
		I	2×10^{-5}	1×10^{-1}	8×10^{-7}	5×10^{-3}
Antimony (51)	Sb 122	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
	Sb 124	S	2×10^{-7}	7×10^{-4}	5×10^{-9}	2×10^{-5}
		I	2×10^{-8}	7×10^{-4}	7×10^{-10}	2×10^{-5}
	Sb 125	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	3×10^{-8}	3×10^{-3}	9×10^{-10}	1×10^{-4}
Argon (18)	A 37	Sub[2]	6×10^{-3}	.....	1×10^{-4}	.....
	A 41	Sub	2×10^{-6}	.....	4×10^{-8}	.....
Arsenic (33)	As 73	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	5×10^{-4}
		I	4×10^{-7}	1×10^{-2}	1×10^{-8}	5×10^{-4}
	As 74	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	5×10^{-5}
		I	1×10^{-7}	2×10^{-3}	4×10^{-9}	5×10^{-5}
	As 76	S	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
		I	1×10^{-7}	6×10^{-4}	3×10^{-9}	2×10^{-5}
	As 77	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Astatine (85)	At 211	S	7×10^{-9}	5×10^{-5}	2×10^{-10}	2×10^{-6}
		I	3×10^{-8}	2×10^{-3}	1×10^{-9}	7×10^{-5}
Barium (56)	Ba 131	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Ba 140	S	1×10^{-7}	8×10^{-4}	4×10^{-9}	3×10^{-5}
		I	4×10^{-8}	7×10^{-4}	1×10^{-9}	2×10^{-5}
Berkelium (97)	Bk 249	S	9×10^{-10}	2×10^{-2}	3×10^{-11}	6×10^{-4}
		I	1×10^{-7}	2×10^{-2}	4×10^{-9}	6×10^{-4}
	Bk 250	S	1×10^{-7}	6×10^{-3}	5×10^{-9}	2×10^{-4}
		I	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
Beryllium (4)	Be 7	S	6×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
		I	1×10^{-6}	5×10^{-2}	4×10^{-8}	2×10^{-3}
Bismuth (83)	Bi 206	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
		I	1×10^{-7}	1×10^{-3}	5×10^{-9}	4×10^{-5}
	Bi 207	S	2×10^{-7}	2×10^{-3}	6×10^{-9}	6×10^{-5}
		I	1×10^{-8}	2×10^{-3}	5×10^{-10}	6×10^{-5}
	Bi 210	S	6×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
		I	6×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
	Bi 212	S	1×10^{-7}	1×10^{-2}	3×10^{-9}	4×10^{-4}
		I	2×10^{-7}	1×10^{-2}	7×10^{-9}	4×10^{-4}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Bromine (35)	Br 82	S	1×10^{-6}	8×10^{-3}	4×10^{-8}	3×10^{-4}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Cadmium (48)	Cd 109	S	5×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
		I	7×10^{-8}	5×10^{-3}	3×10^{-9}	2×10^{-4}
	Cd 115m	S	4×10^{-8}	7×10^{-4}	1×10^{-9}	3×10^{-5}
		I	4×10^{-8}	7×10^{-4}	1×10^{-9}	3×10^{-5}
	Cd 115	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Calcium (20)	Ca 45	S	3×10^{-8}	3×10^{-4}	1×10^{-9}	9×10^{-6}
		I	1×10^{-7}	5×10^{-3}	4×10^{-9}	2×10^{-4}
	Ca 47	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	3×10^{-5}
Californium (98)	Cf 249	S	2×10^{-12}	1×10^{-4}	5×10^{-14}	4×10^{-6}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	2×10^{-5}
	Cf 250	S	5×10^{-12}	4×10^{-4}	2×10^{-13}	1×10^{-5}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	3×10^{-5}
	Cf 251	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
	Cf 252	* S	6×10^{-12}	2×10^{-4}	2×10^{-13}	7×10^{-6}
		* I	3×10^{-11}	2×10^{-4}	1×10^{-12}	7×10^{-6}
	Cf 253	S	8×10^{-10}	4×10^{-3}	3×10^{-11}	1×10^{-4}
		I	8×10^{-10}	4×10^{-3}	3×10^{-11}	1×10^{-4}
	Cf 254	S	5×10^{-12}	4×10^{-6}	2×10^{-13}	1×10^{-7}
		I	5×10^{-12}	4×10^{-6}	2×10^{-13}	1×10^{-7}
Carbon (6)	C 14	S	4×10^{-6}	2×10^{-2}	1×10^{-7}	8×10^{-4}
	(CO_2)	Sub	5×10^{-5}		1×10^{-6}	
Cerium (58)	Ce 141	S	4×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	2×10^{-7}	3×10^{-3}	5×10^{-9}	9×10^{-5}
	Ce 143	S	3×10^{-7}	1×10^{-3}	9×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
	Ce 144	S	1×10^{-8}	3×10^{-4}	3×10^{-10}	1×10^{-5}
		I	6×10^{-9}	3×10^{-4}	2×10^{-10}	1×10^{-5}
Cesium (55)	Cs 131	S	1×10^{-5}	7×10^{-2}	4×10^{-7}	2×10^{-3}
		I	3×10^{-6}	3×10^{-2}	1×10^{-7}	9×10^{-4}
	Cs 134m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	6×10^{-3}
		I	6×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
	Cs 134	S	4×10^{-8}	3×10^{-4}	1×10^{-9}	9×10^{-6}
		I	1×10^{-8}	1×10^{-3}	4×10^{-10}	4×10^{-5}
	Cs 135	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	9×10^{-8}	7×10^{-3}	3×10^{-9}	2×10^{-4}
	Cs 136	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	9×10^{-5}
		I	2×10^{-7}	2×10^{-3}	6×10^{-9}	6×10^{-5}
	Cs 137	S	6×10^{-8}	4×10^{-4}	2×10^{-9}	2×10^{-5}
		I	1×10^{-8}	1×10^{-3}	5×10^{-10}	4×10^{-5}
Chlorine (17)	Cl 36	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
		I	2×10^{-8}	2×10^{-3}	8×10^{-10}	6×10^{-5}
	Cl 38	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	7×10^{-8}	4×10^{-4}
Chromium (24)	Cr 51	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	2×10^{-6}	5×10^{-2}	8×10^{-8}	2×10^{-3}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Cobalt (27)	Co 57	S	3×10^{-6}	2×10^{-2}	1×10^{-7}	5×10^{-4}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
	Co 58m	S	2×10^{-5}	8×10^{-2}	6×10^{-7}	3×10^{-3}
		I	9×10^{-6}	6×10^{-2}	3×10^{-7}	2×10^{-3}
	Co 58	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-8}	3×10^{-3}	2×10^{-9}	9×10^{-5}
	Co 60	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	5×10^{-5}
		I	9×10^{-9}	1×10^{-3}	3×10^{-10}	3×10^{-5}
Copper (29)	Cu 64	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	3×10^{-4}
		I	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
Curium (96)	Cm 242	S	1×10^{-10}	7×10^{-4}	4×10^{-12}	2×10^{-5}
		I	2×10^{-10}	7×10^{-4}	6×10^{-12}	2×10^{-5}
	Cm 243	S	6×10^{-12}	1×10^{-4}	2×10^{-13}	5×10^{-6}
		I	1×10^{-10}	7×10^{-4}	3×10^{-12}	2×10^{-5}
	Cm 244	S	9×10^{-12}	2×10^{-4}	3×10^{-13}	7×10^{-6}
		I	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
	Cm 245	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Cm 246	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	Cm 247	S	5×10^{-12}	1×10^{-4}	2×10^{-13}	4×10^{-6}
		I	1×10^{-10}	6×10^{-4}	4×10^{-12}	2×10^{-5}
	Cm 248	S	6×10^{-13}	1×10^{-5}	2×10^{-14}	4×10^{-7}
		I	1×10^{-11}	4×10^{-5}	4×10^{-13}	1×10^{-6}
	Cm 249	S	1×10^{-5}	6×10^{-2}	4×10^{-7}	2×10^{-3}
		I	1×10^{-5}	6×10^{-2}	4×10^{-7}	2×10^{-3}
Dysprosium (66)	Dy 165	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	7×10^{-8}	4×10^{-4}
	Dy 166	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
Einsteinium (99)	Es 253	S	8×10^{-10}	7×10^{-4}	3×10^{-11}	2×10^{-5}
		I	6×10^{-10}	7×10^{-4}	2×10^{-11}	2×10^{-5}
	Es 254m	S	5×10^{-9}	5×10^{-4}	2×10^{-10}	2×10^{-5}
		I	6×10^{-9}	5×10^{-4}	2×10^{-10}	2×10^{-5}
	Es 254	S	2×10^{-11}	4×10^{-4}	6×10^{-13}	1×10^{-5}
		I	1×10^{-10}	4×10^{-4}	4×10^{-12}	1×10^{-5}
	Es 255	S	5×10^{-10}	8×10^{-4}	2×10^{-11}	3×10^{-5}
		I	4×10^{-10}	8×10^{-4}	1×10^{-11}	3×10^{-5}
Erbium (68)	Er 169	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	4×10^{-7}	3×10^{-3}	1×10^{-8}	9×10^{-5}
	Er 171	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Europium (63)	Eu 152 ($T/2 = 9.2$ hrs)	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Eu 152 ($T/2 = 13$ yrs)	S	1×10^{-8}	2×10^{-3}	4×10^{-10}	8×10^{-5}
		I	2×10^{-8}	2×10^{-3}	6×10^{-10}	8×10^{-5}
	Eu 154	S	4×10^{-9}	6×10^{-4}	1×10^{-10}	2×10^{-5}
		I	7×10^{-9}	6×10^{-4}	2×10^{-10}	2×10^{-5}
	Eu 155	S	9×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}
		I	7×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Fermium (100)	Fm 254	S	6×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
		I	7×10^{-8}	4×10^{-3}	2×10^{-9}	1×10^{-4}
	Fm 255	S	2×10^{-8}	1×10^{-3}	6×10^{-10}	3×10^{-5}
		I	1×10^{-8}	1×10^{-3}	4×10^{-10}	3×10^{-5}
	Fm 256	S	3×10^{-9}	3×10^{-5}	1×10^{-10}	9×10^{-7}
		I	2×10^{-9}	3×10^{-5}	6×10^{-11}	9×10^{-7}
Fluorine (9)	F 18	S	5×10^{-6}	2×10^{-2}	2×10^{-7}	8×10^{-4}
		I	3×10^{-6}	1×10^{-2}	9×10^{-8}	5×10^{-4}
Gadolinium (64)	Gd 153	S	2×10^{-7}	6×10^{-3}	8×10^{-9}	2×10^{-4}
		I	9×10^{-8}	6×10^{-3}	3×10^{-9}	2×10^{-4}
	Gd 159	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Gallium (31)	Ga 72	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
Germanium (32)	Ge 71	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	6×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
Gold (79)	Au 196	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	6×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
	Au 198	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Au 199	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	8×10^{-7}	4×10^{-3}	3×10^{-8}	2×10^{-4}
Hafnium (72)	Hf 181	S	4×10^{-8}	2×10^{-3}	1×10^{-9}	7×10^{-5}
		I	7×10^{-8}	2×10^{-3}	3×10^{-9}	7×10^{-5}
Holmium (67)	Ho 166	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
Hydrogen (1)	H3	S	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
		I	5×10^{-6}	1×10^{-1}	2×10^{-7}	3×10^{-3}
		Sub	2×10^{-3}		4×10^{-5}	
Indium (49)	In 113m	S	8×10^{-6}	4×10^{-2}	3×10^{-7}	1×10^{-3}
		I	7×10^{-6}	4×10^{-2}	2×10^{-7}	1×10^{-3}
	In 114m	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	2×10^{-8}	5×10^{-4}	7×10^{-10}	2×10^{-5}
	In 115m	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	4×10^{-4}
	In 115	S	2×10^{-7}	3×10^{-3}	9×10^{-9}	9×10^{-5}
		I	3×10^{-8}	3×10^{-3}	1×10^{-9}	9×10^{-5}
Iodine (53)	I 125	S	5×10^{-9}	4×10^{-5}	8×10^{-11}	2×10^{-7}
		I	2×10^{-7}	6×10^{-3}	6×10^{-9}	2×10^{-4}
	I 126	S	8×10^{-9}	5×10^{-5}	9×10^{-11}	3×10^{-7}
		I	3×10^{-7}	3×10^{-3}	1×10^{-8}	9×10^{-5}
	I 129	S	2×10^{-9}	1×10^{-5}	2×10^{-11}	6×10^{-8}
		I	7×10^{-8}	6×10^{-3}	2×10^{-9}	2×10^{-4}
	I 131	S	9×10^{-9}	6×10^{-5}	1×10^{-10}	3×10^{-7}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	I 132	S	2×10^{-7}	2×10^{-3}	3×10^{-9}	8×10^{-6}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	I 133	S	3×10^{-8}	2×10^{-4}	4×10^{-10}	1×10^{-6}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
	I 134	S	5×10^{-7}	4×10^{-3}	6×10^{-9}	2×10^{-5}

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(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Iodine (53)	I 134	I	3×10^{-6}	2×10^{-2}	1×10^{-7}	6×10^{-4}
	I 135	S	1×10^{-7}	7×10^{-4}	1×10^{-9}	4×10^{-6}
		I	4×10^{-7}	2×10^{-3}	1×10^{-10}	7×10^{-5}
Iridium (77)	Ir 190	S	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Ir 192	S	1×10^{-7}	1×10^{-3}	4×10^{-9}	4×10^{-5}
		I	3×10^{-9}	1×10^{-3}	9×10^{-10}	4×10^{-5}
	Ir 194	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	5×10^{-9}	2×10^{-5}
Iron (26)	Fe 55	S	9×10^{-7}	2×10^{-2}	3×10^{-8}	8×10^{-4}
		I	1×10^{-6}	7×10^{-2}	3×10^{-8}	2×10^{-3}
	Fe 59	S	1×10^{-7}	2×10^{-3}	5×10^{-9}	6×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	5×10^{-5}
Krypton (36)	Kr 85m	Sub	6×10^{-6}	....	1×10^{-7}	....
	Kr 85	Sub	1×10^{-5}	....	3×10^{-7}	....
	Kr 87	Sub	1×10^{-6}	....	2×10^{-8}	....
	Kr 88	Sub	1×10^{-6}	....	2×10^{-8}	....
Lanthanum (57)	La 140	S	2×10^{-7}	7×10^{-4}	5×10^{-9}	2×10^{-5}
		I	1×10^{-7}	7×10^{-4}	4×10^{-9}	2×10^{-5}
Lead (82)	Pb 203	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	4×10^{-4}
	Pb 210	S	1×10^{-10}	4×10^{-6}	4×10^{-12}	1×10^{-7}
		I	2×10^{-10}	5×10^{-3}	8×10^{-12}	2×10^{-4}
	Pb 212	S	2×10^{-8}	6×10^{-4}	6×10^{-10}	2×10^{-5}
		I	2×10^{-8}	5×10^{-4}	7×10^{-10}	2×10^{-5}
Lutetium (71)	Lu 177	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Manganese (25)	Mn 52	S	2×10^{-7}	1×10^{-3}	7×10^{-9}	3×10^{-5}
		I	1×10^{-7}	9×10^{-4}	5×10^{-9}	3×10^{-5}
	Mn 54	S	4×10^{-7}	4×10^{-3}	1×10^{-8}	1×10^{-4}
		I	4×10^{-8}	3×10^{-3}	1×10^{-9}	1×10^{-4}
	Mn 56	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Mercury (80)	Hg 197m	S	7×10^{-7}	6×10^{-3}	3×10^{-8}	2×10^{-4}
		I	8×10^{-7}	5×10^{-3}	3×10^{-8}	[illegible]
	Hg 197	S	1×10^{-6}	9×10^{-3}	4×10^{-8}	2×10^{-4}
		I	2×10^{-6}	1×10^{-2}	9×10^{-8}	5×10^{-4}
	Hg 203	S	7×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
Molybdenum (42)	Mo 99	S	7×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
		I	2×10^{-7}	1×10^{-3}	7×10^{-9}	4×10^{-5}
Neodymium (60)	Nd 144	S	8×10^{-11}	2×10^{-3}	3×10^{-12}	7×10^{-5}
		I	3×10^{-10}	2×10^{-3}	1×10^{-11}	8×10^{-5}
	Nd 147	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	2×10^{-3}	8×10^{-9}	6×10^{-5}
	Nd 149	S	2×10^{-6}	8×10^{-3}	6×10^{-8}	3×10^{-4}
		I	1×10^{-6}	8×10^{-3}	5×10^{-8}	2×10^{-4}

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(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Neptunium (93)	Np 237	S	4×10^{-12}	9×10^{-5}	1×10^{-13}	3×10^{-6}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	2×10^{-5}
	Np 239	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	7×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
Nickel (28)	Ni 59	S	5×10^{-7}	6×10^{-3}	2×10^{-8}	2×10^{-4}
		I	8×10^{-7}	6×10^{-2}	3×10^{-8}	2×10^{-3}
	Ni 63	S	6×10^{-8}	8×10^{-4}	2×10^{-9}	2×10^{-5}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	7×10^{-4}
	Ni 65	S	9×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Niobium (Columbium) (41)	Nb 93m	S	1×10^{-7}	1×10^{-2}	4×10^{-9}	4×10^{-4}
		I	2×10^{-7}	1×10^{-2}	5×10^{-9}	4×10^{-4}
	Nb 95	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	1×10^{-7}	3×10^{-3}	3×10^{-8}	1×10^{-4}
	Nb 97	S	6×10^{-6}	2×10^{-2}	2×10^{-7}	9×10^{-4}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
Osmium (76)	Os 185	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	7×10^{-5}
	Os 191m	S	2×10^{-5}	7×10^{-2}	6×10^{-7}	2×10^{-3}
		I	9×10^{-6}	7×10^{-2}	2×10^{-7}	2×10^{-3}
	Os 191	S	1×10^{-6}	5×10^{-3}	4×10^{-8}	2×10^{-4}
		I	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
	Os 193	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	3×10^{-7}	2×10^{-3}	9×10^{-9}	5×10^{-5}
Palladium (46)	Pd 103	S	1×10^{-6}	1×10^{-2}	5×10^{-8}	3×10^{-4}
		I	7×10^{-7}	8×10^{-3}	3×10^{-8}	3×10^{-4}
	Pd 109	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
Phosphorus (15)	P 32	S	7×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	8×10^{-8}	7×10^{-4}	3×10^{-9}	2×10^{-5}
Platinum (78)	Pt 191	S	[illegible]	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
	Pt 193m	S	7×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
	Pt 193 *	S	1×10^{-6}	3×10^{-2}	4×10^{-8}	9×10^{-4}
		I	3×10^{-7}	5×10^{-2}	1×10^{-8}	2×10^{-3}
	Pt 197m	S	6×10^{-6}	3×10^{-2}	2×10^{-7}	1×10^{-3}
		I	5×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
	Pt 197	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Plutonium (94)	Pu 238	S	2×10^{-12}	1×10^{-4}	7×10^{-14}	5×10^{-6}
		I	3×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 239	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 240	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	8×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 241	S	9×10^{-11}	7×10^{-3}	3×10^{-12}	2×10^{-4}
		I	4×10^{-8}	4×10^{-2}	1×10^{-9}	1×10^{-3}

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(See footnotes on page 20-15)

Element (atomic number)	Isotope[1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Plutonium (94)	Pu 242	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	5×10^{-6}
		I	4×10^{-11}	9×10^{-4}	1×10^{-12}	3×10^{-5}
	Pu 243	S	2×10^{-6}	1×10^{-2}	6×10^{-8}	3×10^{-4}
		I	2×10^{-6}	1×10^{-2}	8×10^{-8}	3×10^{-4}
	Pu 244	S	2×10^{-12}	1×10^{-4}	6×10^{-14}	4×10^{-6}
		I	3×10^{-11}	3×10^{-4}	1×10^{-12}	1×10^{-5}
Polonium (84)	Po 210	S	5×10^{-10}	2×10^{-5}	2×10^{-11}	7×10^{-7}
		I	2×10^{-10}	8×10^{-4}	7×10^{-12}	3×10^{-5}
Potassium (19)	K 42	S	2×10^{-6}	9×10^{-3}	7×10^{-8}	3×10^{-4}
		I	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
Praseodymium (59)	Pr 142	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	2×10^{-7}	9×10^{-4}	5×10^{-9}	3×10^{-5}
	Pr 143	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	5×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	5×10^{-5}
Promethium (61)	Pm 147	S	6×10^{-8}	6×10^{-3}	2×10^{-9}	2×10^{-4}
		I	1×10^{-7}	6×10^{-3}	3×10^{-9}	2×10^{-4}
	Pm 149	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
Protoactinium (91)	Pa 230	S	2×10^{-9}	7×10^{-3}	6×10^{-11}	2×10^{-4}
		I	8×10^{-10}	7×10^{-3}	3×10^{-11}	2×10^{-4}
	Pa 231	S	1×10^{-12}	3×10^{-5}	4×10^{-14}	9×10^{-7}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	2×10^{-5}
	Pa 233	S	6×10^{-7}	4×10^{-3}	2×10^{-8}	1×10^{-4}
		I	2×10^{-7}	3×10^{-3}	6×10^{-9}	1×10^{-4}
Radium (88)	Ra 223	S	2×10^{-9}	2×10^{-5}	6×10^{-11}	7×10^{-7}
		I	2×10^{-10}	1×10^{-4}	8×10^{-12}	4×10^{-6}
	Ra 224	S	5×10^{-9}	7×10^{-5}	2×10^{-10}	2×10^{-6}
		I	7×10^{-10}	2×10^{-4}	2×10^{-11}	5×10^{-6}
	Ra 226	S	3×10^{-11}	4×10^{-7}	3×10^{-12}	3×10^{-8}
		I	5×10^{-11}	9×10^{-4}	2×10^{-12}	3×10^{-5}
	Ra 228	S	7×10^{-11}	8×10^{-7}	2×10^{-12}	3×10^{-8}
		I	4×10^{-11}	7×10^{-4}	1×10^{-12}	3×10^{-5}
Radon (86)	Rn 220	S	3×10^{-7}	....	1×10^{-8}	....
	Rn 222	S	1×10^{-7}	....	3×10^{-9}	....
Rhenium (75)	Re 183	S	3×10^{-6}	2×10^{-2}	9×10^{-8}	6×10^{-4}
		I	2×10^{-7}	8×10^{-3}	5×10^{-9}	3×10^{-4}
	Re 186	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Re 187	S	9×10^{-6}	7×10^{-2}	3×10^{-7}	3×10^{-3}
		I	5×10^{-7}	4×10^{-2}	2×10^{-8}	2×10^{-3}
	Re 188	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
Rhodium (45)	Rh 103m	S	8×10^{-5}	4×10^{-1}	3×10^{-6}	1×10^{-2}
		I	6×10^{-5}	3×10^{-1}	2×10^{-6}	1×10^{-2}
	Rh 105	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Rubidium (37)	Rb 86	S	3×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
		I	7×10^{-8}	7×10^{-4}	2×10^{-9}	2×10^{-5}
	Rb 87	S	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	7×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}

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Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope[1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Ruthenium (44)	Ru 97	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-6}	1×10^{-2}	6×10^{-8}	3×10^{-4}
	Ru 103	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	8×10^{-8}	2×10^{-3}	3×10^{-9}	8×10^{-5}
	Ru 105	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
	Ru 106	S	8×10^{-8}	4×10^{-4}	3×10^{-9}	1×10^{-5}
		I	6×10^{-9}	3×10^{-4}	2×10^{-10}	1×10^{-5}
Samarium (62)	Sm 147	S	7×10^{-11}	2×10^{-3}	2×10^{-12}	6×10^{-5}
		I	3×10^{-10}	2×10^{-3}	9×10^{-12}	7×10^{-5}
	Sm 151	S	6×10^{-8}	1×10^{-2}	2×10^{-9}	4×10^{-4}
		I	1×10^{-7}	1×10^{-2}	5×10^{-9}	4×10^{-4}
	Sm 153	S	5×10^{-7}	2×10^{-3}	2×10^{-8}	8×10^{-5}
		I	4×10^{-7}	2×10^{-3}	1×10^{-8}	8×10^{-5}
Scandium (21)	Sc 46	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
		I	2×10^{-8}	1×10^{-3}	8×10^{-10}	4×10^{-5}
	Sc 47	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
		I	5×10^{-7}	3×10^{-3}	2×10^{-8}	9×10^{-5}
	Sc 48	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
Selenium (34)	Se 75	S	1×10^{-6}	9×10^{-3}	4×10^{-8}	3×10^{-4}
		I	1×10^{-7}	8×10^{-3}	4×10^{-9}	3×10^{-4}
Silicon (14)	Si 31	S	6×10^{-6}	3×10^{-2}	2×10^{-7}	9×10^{-4}
		I	1×10^{-6}	6×10^{-3}	3×10^{-8}	2×10^{-4}
Silver (47)	Ag 105	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	8×10^{-8}	3×10^{-3}	3×10^{-9}	1×10^{-4}
	Ag 110m	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	1×10^{-8}	9×10^{-4}	3×10^{-10}	3×10^{-5}
	Ag 111	S	3×10^{-7}	1×10^{-3}	1×10^{-8}	4×10^{-5}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	4×10^{-5}
Sodium (11)	Na 22	S	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
		I	9×10^{-9}	9×10^{-4}	3×10^{-10}	3×10^{-5}
	Na 24	S	1×10^{-6}	6×10^{-3}	4×10^{-8}	2×10^{-4}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}
Strontium (38)	Sr 85m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	7×10^{-3}
		I	3×10^{-5}	2×10^{-1}	1×10^{-6}	7×10^{-3}
	Sr 85	S	2×10^{-7}	3×10^{-3}	8×10^{-9}	1×10^{-4}
		I	1×10^{-7}	5×10^{-3}	4×10^{-9}	2×10^{-4}
	Sr 89	S	3×10^{-8}	3×10^{-4}	3×10^{-10}	3×10^{-6}
		I	4×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
	Sr 90	S	1×10^{-9}	1×10^{-5}	3×10^{-11}	3×10^{-7}
		I	5×10^{-9}	1×10^{-3}	2×10^{-10}	4×10^{-5}
	Sr 91	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	1×10^{-3}	9×10^{-9}	5×10^{-5}
	Sr 92	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
Sulfur (16)	S 35	S	3×10^{-7}	2×10^{-3}	9×10^{-9}	6×10^{-5}
		I	3×10^{-7}	8×10^{-3}	9×10^{-9}	3×10^{-4}
Tantalum (73)	Ta 182	S	4×10^{-8}	1×10^{-3}	1×10^{-9}	4×10^{-5}
		I	2×10^{-8}	1×10^{-3}	7×10^{-10}	4×10^{-5}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Technetium (43)	Tc 96m	S	8×10^{-5}	4×10^{-1}	3×10^{-6}	1×10^{-2}
		I	3×10^{-5}	3×10^{-1}	1×10^{-6}	1×10^{-2}
	Tc 96	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	2×10^{-7}	1×10^{-3}	8×10^{-9}	5×10^{-5}
	Tc 97m	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	2×10^{-7}	5×10^{-3}	5×10^{-9}	2×10^{-4}
	Tc 97	S	1×10^{-5}	5×10^{-2}	4×10^{-7}	2×10^{-3}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	8×10^{-4}
	Tc 99m	S	4×10^{-5}	2×10^{-1}	1×10^{-6}	6×10^{-3}
		I	1×10^{-5}	8×10^{-2}	5×10^{-7}	3×10^{-3}
	Tc 99	S	2×10^{-6}	1×10^{-2}	7×10^{-8}	3×10^{-4}
		I	6×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
Tellurium (52)	Te 125m	S	4×10^{-7}	5×10^{-3}	1×10^{-8}	2×10^{-4}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
	Te 127m	S	1×10^{-7}	2×10^{-3}	5×10^{-9}	6×10^{-5}
		I	4×10^{-8}	2×10^{-3}	1×10^{-9}	5×10^{-5}
	Te 127	S	2×10^{-6}	8×10^{-3}	6×10^{-8}	3×10^{-4}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	Te 129m	S	8×10^{-8}	1×10^{-3}	3×10^{-9}	3×10^{-5}
		I	3×10^{-8}	6×10^{-4}	1×10^{-9}	2×10^{-5}
	Te 129	S	5×10^{-6}	2×10^{-2}	2×10^{-7}	8×10^{-4}
		I	4×10^{-6}	2×10^{-2}	1×10^{-7}	8×10^{-4}
	Te 131m	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	4×10^{-5}
	Te 132	S	2×10^{-7}	9×10^{-4}	7×10^{-9}	3×10^{-5}
		I	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
Terbium (65)	Tb 160	S	1×10^{-7}	1×10^{-3}	3×10^{-9}	4×10^{-5}
		I	3×10^{-8}	1×10^{-3}	1×10^{-9}	4×10^{-5}
Thallium (81)	Tl 200	S	3×10^{-6}	1×10^{-2}	9×10^{-8}	4×10^{-4}
		I	1×10^{-6}	7×10^{-3}	4×10^{-8}	2×10^{-4}
	Tl 201	S	2×10^{-6}	9×10^{-3}	7×10^{-8}	3×10^{-4}
		I	9×10^{-7}	5×10^{-3}	3×10^{-8}	2×10^{-4}
	Tl 202	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	2×10^{-7}	2×10^{-3}	8×10^{-9}	7×10^{-5}
	Tl 204	S	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	3×10^{-8}	2×10^{-3}	9×10^{-10}	6×10^{-5}
Thorium (90)	* Th 227	S	3×10^{-10}	5×10^{-4}	1×10^{-11}	2×10^{-5}
		I	2×10^{-10}	5×10^{-4}	6×10^{-12}	2×10^{-5}
	Th 228	S	9×10^{-12}	2×10^{-4}	3×10^{-13}	7×10^{-6}
		I	6×10^{-12}	4×10^{-4}	2×10^{-13}	1×10^{-5}
	Th 230	S	2×10^{-12}	5×10^{-5}	8×10^{-14}	2×10^{-6}
		I	1×10^{-11}	9×10^{-4}	3×10^{-13}	3×10^{-5}
	* Th 231	S	1×10^{-6}	7×10^{-3}	5×10^{-8}	2×10^{-4}
		I	1×10^{-6}	7×10^{-3}	4×10^{-8}	2×10^{-4}
	Th 232	S	3×10^{-11}	5×10^{-5}	1×10^{-12}	2×10^{-6}
		I	3×10^{-11}	1×10^{-3}	1×10^{-12}	4×10^{-5}
	** Th natural	S	6×10^{-11}	6×10^{-5}	2×10^{-12}	2×10^{-6}
		I	6×10^{-11}	6×10^{-4}	2×10^{-12}	2×10^{-5}

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APPENDIX B

Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

Element (atomic number)	Isotope [1]	†	Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Thorium (90)	Th 234	S	6×10^{-8}	5×10^{-4}	2×10^{-9}	2×10^{-5}
		I	3×10^{-8}	5×10^{-4}	1×10^{-9}	2×10^{-5}
Thulium (69)	Tm 170	S	4×10^{-8}	1×10^{-3}	1×10^{-9}	5×10^{-5}
		I	3×10^{-8}	1×10^{-3}	1×10^{-9}	5×10^{-5}
	Tm 171	S	1×10^{-7}	1×10^{-2}	4×10^{-9}	5×10^{-4}
		I	2×10^{-7}	1×10^{-2}	8×10^{-9}	5×10^{-4}
Tin (50)	Sn 113	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	9×10^{-5}
		I	5×10^{-8}	2×10^{-3}	2×10^{-9}	8×10^{-5}
	Sn 125	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	8×10^{-8}	5×10^{-4}	3×10^{-9}	2×10^{-5}
Tungsten (Wolfram) (74)	W 181	S	2×10^{-6}	1×10^{-2}	8×10^{-8}	4×10^{-4}
		I	1×10^{-7}	1×10^{-2}	4×10^{-9}	3×10^{-4}
	W 185	S	8×10^{-7}	4×10^{-3}	3×10^{-8}	1×10^{-4}
		I	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
	W 187	S	4×10^{-7}	2×10^{-3}	2×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
Uranium (92)	U 230	S	3×10^{-10}	1×10^{-4}	1×10^{-11}	5×10^{-6}
		I	1×10^{-10}	1×10^{-4}	4×10^{-12}	5×10^{-6}
	U 232	S	1×10^{-10}	8×10^{-4}	3×10^{-12}	3×10^{-5}
		I	3×10^{-11}	8×10^{-4}	9×10^{-13}	3×10^{-5}
	U 233	S	5×10^{-10}	9×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}
	** U 234	S[3]	6×10^{-10}	9×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	9×10^{-4}	4×10^{-12}	3×10^{-5}
	** U 235	S[3]	5×10^{-10}	8×10^{-4}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	8×10^{-4}	4×10^{-12}	3×10^{-5}
	U 236	S	6×10^{-10}	1×10^{-3}	2×10^{-11}	3×10^{-5}
		I	1×10^{-10}	1×10^{-3}	4×10^{-12}	3×10^{-5}
	** U 238	S[3]	7×10^{-11}	1×10^{-3}	3×10^{-12}	4×10^{-5}
		I	1×10^{-10}	1×10^{-3}	5×10^{-12}	4×10^{-5}
	U 240	S	2×10^{-7}	1×10^{-3}	8×10^{-9}	3×10^{-5}
		I	2×10^{-7}	1×10^{-3}	6×10^{-9}	3×10^{-5}
	** U-natural	S[3]	1×10^{-10}	1×10^{-3}	5×10^{-12}	3×10^{-5}
		I	1×10^{-10}	1×10^{-3}	5×10^{-12}	3×10^{-5}
Vanadium (23)	V 48	S	2×10^{-7}	9×10^{-4}	6×10^{-9}	3×10^{-5}
		I	6×10^{-8}	8×10^{-4}	2×10^{-9}	3×10^{-5}
Xenon (54)	Xe 131m	Sub	2×10^{-5}	....	4×10^{-7}	....
	Xe 133	Sub	1×10^{-5}	....	3×10^{-7}	....
	Xe 133m	Sub	1×10^{-5}	....	3×10^{-7}	....
	Xe 135	Sub	4×10^{-6}	....	1×10^{-7}	....
Ytterbium (70)	Yb 175	S	7×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
		I	6×10^{-7}	3×10^{-3}	2×10^{-8}	1×10^{-4}
Yttrium (39)	Y 90	S	1×10^{-7}	6×10^{-4}	4×10^{-9}	2×10^{-5}
		I	1×10^{-7}	6×10^{-4}	3×10^{-9}	2×10^{-5}
	Y 91m	S	2×10^{-5}	1×10^{-1}	8×10^{-7}	3×10^{-3}
		I	2×10^{-5}	1×10^{-1}	6×10^{-7}	3×10^{-3}
	Y 91	S	4×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
		I	3×10^{-8}	8×10^{-4}	1×10^{-9}	3×10^{-5}
	Y 92	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Y 93	S	2×10^{-7}	8×10^{-4}	6×10^{-9}	3×10^{-5}
		I	1×10^{-7}	8×10^{-4}	5×10^{-9}	3×10^{-5}

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Concentrations in Air and Water Above Natural Background—Continued

(See footnotes on page 20-15)

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Element (atomic number)	Isotope [1]		Table I Column 1 Air (μCi/ml)	Table I Column 2 Water (μCi/ml)	Table II Column 1 Air (μCi/ml)	Table II Column 2 Water (μCi/ml)
Zinc (30)	Zn 65	S	1×10^{-7}	3×10^{-3}	4×10^{-9}	1×10^{-4}
		I	6×10^{-8}	5×10^{-3}	2×10^{-9}	2×10^{-4}
	Zn 69m	S	4×10^{-7}	2×10^{-3}	1×10^{-8}	7×10^{-5}
		I	3×10^{-7}	2×10^{-3}	1×10^{-8}	6×10^{-5}
	Zn 69	S	7×10^{-6}	5×10^{-2}	2×10^{-7}	2×10^{-3}
		I	9×10^{-6}	5×10^{-2}	3×10^{-7}	2×10^{-3}
Zirconium (40)	Zr 93	S	1×10^{-7}	2×10^{-2}	4×10^{-9}	8×10^{-4}
		I	3×10^{-7}	2×10^{-2}	1×10^{-8}	8×10^{-4}
	Zr 95	S	1×10^{-7}	2×10^{-3}	4×10^{-9}	6×10^{-5}
		I	3×10^{-8}	2×10^{-3}	1×10^{-9}	6×10^{-5}
	Zr 97	S	1×10^{-7}	5×10^{-4}	4×10^{-9}	2×10^{-5}
		I	9×10^{-8}	5×10^{-4}	3×10^{-9}	2×10^{-5}
Any single radionuclide not listed above with decay mode other than alpha emission or spontaneous fission and with radioactive half-life less than 2 hours.		Sub	1×10^{-6}		3×10^{-8}	
Any single radionuclide not listed above with decay mode other than alpha emission or spontaneous fission and with radioactive half-life greater than 2 hours.			3×10^{-9}	9×10^{-5}	1×10^{-10}	3×10^{-6}
Any single radionuclide not listed above, which decays by alpha emission or spontaneous fission.			6×10^{-13}	4×10^{-7}	2×10^{-14}	3×10^{-8}

[1] Soluble (S); Insoluble (I).

[2] "Sub" means that values given are for submersion in a semispherical infinite cloud of airborne material.

39 FR 23990

‡ 3. For soluble mixtures of U-238, U-234 and U-235 in air chemical toxicity may be the limiting factor. If the percent by weight (enrichment) of U-235 is less than 5, the concentration value for a 40-hour workweek, Table I, is 0.2 milligrams uranium per cubic meter of air average. For any enrichment, the product of the average concentration and time of exposure during a 40-hour workweek shall not exceed 8×10^{-9} SA µCi-hr/ml, where SA is the specific activity of the uranium inhaled. The concentration value for Table II is 0.007 milligrams uranium per cubic meter of air. The specific activity for natural uranium is 6.77×10^{-7} curies per gram U. The specific activity for other mixtures of U-238, U-235 and U-234, if not known, shall be:

$SA=3.6\times10^{-7}$ curies/gram U U-depleted

$SA=(0.4+0.38E+0.0034E^2)\ 10^{-6}$ $E\geq0.72$

where E is the percentage by weight of U-235, expressed as percent.

* Amended 37 FR 23319.

** Amended 39 FR 23990.

† Amended 38 FR 29314.

‡ Amended 39 FR 25463.

NOTE TO APPENDIX B

25 FR 10914

NOTE: In any case where there is a mixture in air or water of more than one radionuclide, the limiting values for purposes of this Appendix should be determined as follows:

1. If the identity and concentration of each radionuclide in the mixture are known, the limiting values should be derived as follows. Determine, for each radionuclide in the mixture, the ratio between the quantity present in the mixture and the limit otherwise established in Appendix B for the specific radionuclide when not in a mixture. The sum of such ratios for all the radionuclides in the mixture may not exceed "1" (i.e., "unity").

EXAMPLE: If radionuclides A, B, and C are present in concentrations C_A, C_B, and C_C, and if the applicable MPC's, are MPC_A, and MPC_B, and MPC_C respectively, then the concentrations shall be limited so that the following relationship exists

$$\frac{C_A}{MPC_A}+\frac{C_B}{MPC_B}+\frac{C_C}{MPC_C}\leq 1$$

30 FR 15801

2. If either the identity or the concentration of any radionuclide in the mixture is not known, the limiting values for purposes of Appendix B shall be:

a. For purposes of Table I, Col. 1—6×10^{-13}
b. For purposes of Table I, Col. 2—4×10^{-7}
c. For purposes of Table II, Col. 1—2×10^{-14}
d. For purposes of Table II, Col. 2—3×10^{-8}

26 FR 11046

3. If any of the conditions specified below are met, the corresponding values specified below may be used in lieu of those specified in paragraph 2 above.

a. If the identity of each radionuclide in the mixture is known but the concentration of one or more of the radionuclides in the mixture is not known, the concentration limit for the mixture is the limit specified in Appendix "B" for the radionuclide in the mixture having the lowest concentration limit; or

b. If the identity of each radionuclide in the mixture is not known, but it is known that certain radionuclides specified in Appendix "B" are not present in the mixture, the concentration limit for the mixture is the lowest concentration limit specified in Appendix "B" for any radionuclide which is not known to be absent from the mixture; or

30 FR 15801

c. Element (atomic number) and isotope	Table I Column 1 Air (µCi/ml)	Table I Column 2 Water (µCi/ml)	Table II Column 1 Air (µCi/ml)	Table II Column 2 Water (µCi/ml)
If it is known that Sr 90, I 125, I 126, I 129, I 131, (I 133, table II only), Pb 210, Po 210, At 211, Ra 223, Ra 224, Ra 226, Ac 227, Ra 228, Th 230, Pa 231, Th 232, Th-nat, Cm 248, Cf 254, and Fm 256 are not present	....	9×10^{-5}	....	3×10^{-6}
If it is known that Sr 90, I 125, I 126, I 129, (I 131, I 133, table II only), Pb 210, Po 210, Ra 223, Ra 226, Ra 228, Pa 231, Th-nat, Cm 248, Cf 254, and Fm 256 are not present	....	6×10^{-5}	....	2×10^{-6}
If it is known that Sr 90, I 129, (I 125, I 126, I 131, table II only), Pb 210, Ra 226, Ra 228, Cm 248, and Cf 254 are not present	....	2×10^{-5}	....	6×10^{-7}
If it is known that (I 129, table II only), Ra 226, and Ra 228 are not present	....	3×10^{-6}	....	1×10^{-7}
If it is known that alpha-emitters and Sr 90, I 129, Pb 210, Ac 227, Ra 228, Pa 230, Pu 241, and Bk 249 are not present	3×10^{-9}	....	1×10^{-10}	....
If it is known that alpha-emitters and Pb 210, Ac 227, Ra 228, and Pu 241 are not present	3×10^{-10}	....	1×10^{-11}	....
If it is known that alpha-emitters and Ac 227 are not present	3×10^{-11}	....	1×10^{-12}	....
If it is known that Ac 227, Th 230, Pa 231, Pu 238, Pu 239, Pu 240, Pu 242, Pu 244, Cm 248, Cf 249 and Cf 251 are not present	3×10^{-12}	....	1×10^{-13}	....

25 FR 13952

4. If the mixture of radionuclides consists of uranium and its daughter products in ore dust prior to chemical processing of the uranium ore, the values specified below may be used in lieu of those determined in accordance with paragraph 1 above or those specified in paragraphs 2 and 3 above.

39 FR 23990

a. For purposes of Table I, Col. 1—1×10^{-10} µCi/ml gross alpha activity; or 5×10^{-11} µCi/ml natural uranium; or 75 micrograms per cubic meter of air natural uranium.

b. For purposes of Table II, Col. 1—3×10^{-12} µCi/ml gross alpha activity; or 2×10^{-12} µCi/ml natural uranium; or 3 micrograms per cubic meter of air natural uranium.

26 FR 11046

5. For purposes of this note, a radionuclide may be considered as not present in a mixture if (a) the ratio of the concentration of that radionuclide in the mixture (C_A) to the concentration limit for that radionuclide specified in Table II of Appendix B (MPC_A) does not exceed 1/10 (i.e. $\frac{C_A}{MPC_A}\leq\frac{1}{10}$) and (b) the sum of such ratios for all the radionuclides considered as not present in the mixture does not exceed 1/4 (i.e. $\frac{C_A}{MPC_A}+\frac{C_B}{MPC_B}+\ldots\ldots\leq\frac{1}{4}$).

APPENDIX C

Material	Microcuries
Americium-241	.01
Antimony-122	100
Antimony-124	10
Antimony-125	10
Arsenic-73	100
Arsenic-74	10
Arsenic-76	10
Arsenic-77	100
Barium-131	10
*Barium-133	10
Barium-140	10
Bismuth-210	1
Bromine-82	10
Cadmium-109	10
Cadmium-115m	10
Cadmium-115	100
Calcium-45	10
Calcium-47	10
Carbon-14	100
Cerium-141	100
Cerium-143	100
Cerium-144	1
Cesium-131	1,000
Cesium-134m	100
Cesium-134	1
Cesium-135	10
Cesium-136	10
Cesium-137	10
Chlorine-36	10
Chlorine-38	10
Chromium-51	1,000
Cobalt-58m	10
Cobalt-58	10
Cobalt-60	1
Copper-64	100
Dysprosium-165	10
Dysprosium-166	100
Erbium-169	100
Erbium-171	100
Europium-152 9.2 h	100
Europium-152 13 yr	1
Europium-154	1
Europium-155	10
Fluorine-18	1,000
Gadolinium-153	10
Gadolinium-159	100
Gallium-72	10
Germanium-71	100
Gold-198	100
Gold-199	100
Hafnium-181	10
Holmium-166	100
Hydrogen-3	1,000
Indium-113m	100
Indium-114m	10
Indium-115m	100
Indium-115	10
Iodine-125	1
Iodine-126	1
Iodine-129	0.1
Iodine-131	1
Iodine-132	10
Iodine-133	1
Iodine-134	10
Iodine-135	10
Iridium-192	10
Iridium-194	100
Iron-55	100
Iron-59	10
Krypton-85	100
Krypton-87	10
Lanthanum-140	10
Lutetium-177	100
Manganese-52	10
Manganese-54	10
Manganese-56	10
Mercury-197m	100
Mercury-197	100
Mercury-203	10
Molybdenum-99	100
Neodymium-147	100
Neodymium-149	100
Nickel-59	100
Nickel-63	10
Nickel-65	100
Niobium-93m	10
Niobium-95	10
Niobium-97	10
Osmium-185	10
Osmium-191m	100
Osmium-191	100
Osmium-193	100
Palladium-103	100
Palladium-109	100
Phosphorus-32	10
Platinum-191	100
Platinum-193m	100
Platinum-193	100
Platinum-197m	100
Platinum-197	100
Plutonium-239	.01
Polonium-210	0.1
Potassium-42	10
Praseodymium-142	100
Praseodymium-143	100
Promethium-147	10
Promethium-149	10
Radium-226	.01
Rhenium-186	100
Rhenium-188	100
Rhodium-103m	100
Rhodium-105	100
Rubidium-86	10
Rubidium-87	10
Ruthenium-97	100
Ruthenium-103	10
Ruthenium-105	10
Ruthenium-106	1
Samarium-151	10
Samarium-153	100
Scandium-46	10
Scandium-47	100
Scandium-48	10
Selenium-75	10
Silicon-31	100
Silver-105	10
Silver-110m	1
Silver-111	100
Sodium-24	10
Strontium-85	10
Strontium-89	1
Strontium-90	0.1
Strontium-91	10
Strontium-92	10
Sulphur-35	100
Tantalum-182	10
Technetium-96	10
Technetium-97m	100
Technetium-97	100
Technetium-99m	100
Technetium-99	10
Tellurium-125m	10
Tellurium-127m	10
Tellurium-127	100
Tellurium-129m	10
Tellurium-129	100
Tellurium-131m	10
Tellurium-132	10
Terbium-160	10
Thallium-200	100
Thallium-201	100
Thallium-202	100
Thallium-204	10
**Thorium (natural)[1]	100
Thulium-170	10
Thulium-171	10
Tin-113	10
Tin-125	10
Tungsten-181	10
Tungsten-185	10
Tungsten-187	100
**Uranium (natural)[2]	100
Uranium-233	.01
Uranium-234—Uranium-235	.01
Vanadium-48	10
Xenon-131m	1,000
Xenon-133	100
Xenon-135	100
Ytterbium-175	100
Yttrium-90	10
Yttrium-91	10
Yttrium-92	100
Yttrium-93	100
Zinc-65	10
Zinc-69m	100
Zinc-69	1,000
Zirconium-93	10
Zirconium-95	10
Zirconium-97	10
Any alpha emitting radionuclide not listed above or mixtures of alpha emitters of unknown composition	.01
Any radionuclide other than alpha emitting radionuclides, not listed above or mixtures of beta emitters of unknown composition	.1

35 FR 6425

NOTE: For purposes of §§ 20.203 and 20.304, where there is involved a combination of isotopes in known amounts the limit for the combination should be derived as follows: Determine, for each isotope in the combination, the ratio between the quantity present in the combination and the limit otherwise established for the specific isotope when not in combination. The sum of such ratios for all the isotopes in the combination may not exceed "1" (i.e., "unity"). Example: For purposes of § 20.304, if a particular batch contains 20,000 μCi† of Au^{198} and 50,000 μCi† of C^{14}, it may also include not more than 300 μCi† of I^{131}. This limit was determined as follows:

$$\dagger\ \frac{20{,}000\ \mu Ci\ Au^{198}}{100{,}000\ \mu Ci} + \frac{50{,}000\ \mu Ci\ C^{14}}{100{,}000\ \mu Ci} + \frac{300\ \mu Ci\ I^{131}}{1{,}000\ \mu Ci} = 1$$

The denominator in each of the above ratios was obtained by multiplying the figure in the table by 1,000 as provided in § 20.304.

[1] Based on alpha disintegration rate of Th-232, Th-230 and their daughter products.

[2] Based on alpha disintegration rate of U-238, U-234, and U-235.

* Amended 36 FR 16898.

** Amended 39 FR 23990.

† Amended 38 FR 29314.

Appendix D

UNITED STATES NUCLEAR REGULATORY COMMISSION

INSPECTION AND ENFORCEMENT REGIONAL OFFICES

Region	Address	Telephone	
		Daytime	Nights and Holidays
I Connecticut, Delaware, District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont	Region I, USNRC Office of Inspection and Enforcement 631 Park Avenue King of Prussia, Pa. 19406	(215) 337-1150	(215) 337-1150
II* Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, Panama Canal Zone, Puerto Rico, South Carolina, Tennessee, Virginia, Virgin Islands, and West Virginia	Region II, USNRC Office of Inspection and Enforcement 230 Peachtree St., N.W. Suite 818 Atlanta, Ga. 30303	(404) 526-4503	(404) 526-4503
III Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin	Region III, USNRC Office of Inspection and Enforcement 799 Roosevelt Road Glen Ellyn, Ill. 60137	(312) 858-2660	*(312) 739-7711
IV* Arkansas, Colorado, Idaho, Kansas, Louisiana, Montana, Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Utah, and Wyoming	* Region IV, USNRC Office of Inspection and Enforcement 611 Ryan Plaza Drive Suite 1000 Arlington, Texas 76012	*(817) 334-2841	*(817) 334-2841
V Alaska, Arizona, California, Hawaii, Nevada, Oregon, Washington, and U.S. territories and possessions in the Pacific	* Region V, USNRC Office of Inspection and Enforcement 1990 N. California Blvd. Suite 202 Walnut Creek, Calif. 94596	**(415) 486-3141	(415) 273-4237

38 FR 17198

* Amended.
** Amended 39 FR 17972.

NOTE: The reporting and record keeping requirements contained in §§20.205(b) and 20.205(c) and required by §20.401(b) have been approved by GAO under B-180225 (R0054). The approval expires June 30, 1977.

APPENDIX II

2^n TABLE

2^nTABLE

TABLE (2^n values)

Guide for Safe Siding 2^n Table Values

Unknown	Enter 2^n Table with	Select	Leave 2^n Table with
$X_{1/2}$, $t_{1/2}$	2^n	smaller 2^n	n
X, t	2^n	larger 2^n	n
R	n	smaller n	2^n
R_o	n	larger n	2^n

n	2^n	n	2^n	n	2^n	n	2^n
0.0	1.000	2.0	4.000	4.0	16.00	6.0	64.0
0.1	1.072	2.1	4.280	4.1	17.20	6.1	68.0
0.2	1.149	2.2	4.590	4.2	18.40	6.2	74.0
0.3	1.232	2.3	4.950	4.3	19.70	6.3	78.0
0.4	1.320	2.4	5.280	4.4	21.20	6.4	84.0
0.5	1.415	2.5	5.650	4.5	22.60	6.5	90.0
0.6	1.515	2.6	6.050	4.6	24.20	6.6	97.0
0.7	1.627	2.7	6.500	4.7	25.90	6.7	104
0.8	1.743	2.8	6.950	4.8	27.80	6.8	112
0.9	1.868	2.9	7.450	4.9	29.80	6.9	119
1.0	2.000	3.0	8.000	5.0	32.0	7.0	128
1.1	2.150	3.1	8.55	5.1	34.2	7.1	136
1.2	2.300	3.2	9.18	5.2	36.7	7.2	146
1.3	2.470	3.3	9.85	5.3	39.2	7.3	157
1.4	2.640	3.4	10.60	5.4	42.1	7.4	170
1.5	2.830	3.5	11.30	5.5	45.2	7.5	181
1.6	3.030	3.6	12.10	5.6	48.4	7.6	194
1.7	3.250	3.7	13.00	5.7	52.0	7.7	206
1.8	3.480	3.8	13.90	5.8	56.0	7.8	220
1.9	3.730	3.9	15.00	5.9	60.0	7.9	240

The use of the guide for safe siding depends on the variable which is unknown. For example, if the thickness is unknown, find X in the "unknown" column, read to the right. Find that you should enter the table with 2^n, select the larger value of 2^n, select the larger value of 2^n and leave with the value of n corresponding to that largest value.

n	2^n	n	2^n	n	2^n	n	2^n
8.0	256	11.0	2048	14.0	16384	17.0	131072
8.1	272	11.1	2200	14.1	17600	17.1	139000
8.2	292	11.2	2360	14.2	18850	17.2	150000
8.3	312	11.3	2530	14.3	20200	17.3	162000
8.4	338	11.4	2640	14.4	21800	17.4	174000
8.5	360	11.5	2900	14.5	23200	17.5	186000
8.6	385	11.6	3110	14.6	24800	17.6	199000
8.7	415	11.7	3330	14.7	26600	17.7	211000
8.8	445	11.8	3560	14.8	28500	17.8	228000
8.9	480	11.9	3820	14.9	30600	17.9	246000
9.0	512	12.0	4096	15.0	32768	18.0	262000
9.1	550	12.1	4390	15.1	35100	18.1	279000
9.2	580	12.2	4700	15.2	37600	18.2	299000
9.3	630	12.3	5070	15.3	40200	18.3	320000
9.4	680	12.4	5420	15.4	43200	18.4	327000
9.5	720	12.5	5790	15.5	46400	18.5	369000
9.6	770	12.6	6200	15.6	49600	18.6	395000
9.7	830	12.7	6760	15.7	53300	18.7	426000
9.8	890	12.8	7120	15.8	57400	18.8	456000
9.9	950	12.9	7630	15.9	61600	18.9	492000
10.0	1024	13.0	8192	16.0	65536	19.0	525000
10.1	1100	13.1	8760	16.1	69700	19.1	564000
10.2	1180	13.2	9410	16.2	75800	19.2	594000
10.3	1260	13.3	10100	16.3	80000	19.3	646000
10.4	1350	13.4	10870	16.4	86200	19.4	696000
10.5	1455	13.5	11600	16.5	92300	19.5	738000
10.6	1560	13.6	12900	16.6	99500	19.6	788000
10.7	1670	13.7	13300	16.7	107000	19.7	852000
10.8	1780	13.8	14200	16.8	115000	19.8	903000
10.9	1920	13.9	15400	16.9	122000	19.9	974000
						20.0	1050000

*U.S. GOVERNMENT PRINTING OFFICE: 1975 621-905/2864 1-3